

Waterpower in Lowell: Engineering and Industry in Nineteenth-Century America is published by Johns Hopkins University Press in Baltimore, Maryland. The author, Patrick M. Malone, is Professor of American Civilization and Urban Studies and Director of the Urban Studies Program at Brown University. The book is a case study of the development of waterpower in Lowell, Massachusetts. Its thesis is that waterpower was the resource that made possible America's first great industrial city. Lowell became a thriving center for textile production and machine building when Boston capitalists harnessed the energy of Pawtucket Falls, on the Merrimack River. The city's remarkable economic success, efficient workforce, attractive architecture, and tree-lined canals made it a model for other communities.

Much of the book focuses on James B. Francis, an English immigrant who joined Lowell's Proprietors of Locks and Canals as a young man in 1834 and rose rapidly to become both the company's chief engineer and its managing executive. He was arguably the finest engineer in nineteenth-century America. For almost fifty years, his technical expertise guided the expansion and refinement of the two level canal system and the use of scientific engineering for flow measurement and turbine design. His promotion of corporate landscaping enhanced the built environment of Lowell.

The intended audience includes readers of American history, college students in courses dealing with urban or technological history, and visitors to the popular Lowell National Historical Park. The first chapter sets the stage for the creation of a new city by the falls. Then there are four chapters covering the period from 1821 to 1885, as well as a thematic chapter on scientific engineering and a postscript that brings the story to the present.

This is the first book about Lowell to make extensive use of material evidence, technical drawings, and engineering notebooks. Among its original contributions are close investigations of the role of the chief engineer in a power company that served multiple manufacturing complexes; the origins of American industrial research; the environmental impacts of waterpower development; the overlooked importance of hybrid steam/waterpower systems; and the occasionally tense relations between Lowell's citizenry and its corporations.

Online Notes for *Waterpower in Lowell*

In order to reduce the length and cost of *Waterpower in Lowell*, the author and Robert J. Brugger, his editor at Johns Hopkins University Press, decided to limit the published notes to the quotations in the book. A much more complete set of notes (full citations) would be made available online for research scholars and other serious readers. You are now reading those online notes, which are stored at the American Textile History Museum (Chace Catalog) and at the Center for Lowell History of the University of Massachusetts Lowell. The author thanks archivists Clare Sheridan and Martha Mayo for including the complete notes to *Waterpower in Lowell* in the websites of their respective institutions. He is also grateful to Rebekah Souder-Russo, a student at Brown University, for helping him to compile the notes and put them in proper form for online use. Brown University generously provided a Humanities Research Grant to pay for this compilation. The online notes are referenced by page and paragraph number. They are much more extensive than the published notes, which are referenced by numbers in the printed text. Everything in the published notes is included here, but it is referenced by page and paragraph for online use. The paragraph numbers (#) refer to the order of paragraphs on a given page. If a paragraph continues to the next page, it is listed as the first paragraph on that page (not on the page where it begins).

Abbreviations in Citations

ATHM	American Textile History Museum
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
CLH	Center for Lowell History, University of Massachusetts Lowell
<i>CORHA</i>	<i>Contributions of the Old Residents' Historical Association, Lowell, Mass.</i>
JBF	James B. Francis
<i>LHE</i>	James B. Francis, <i>Lowell Hydraulic Experiments</i>
LNHP	Lowell National Historical Park
MMC	Merrimack Manufacturing Company
MHS	Massachusetts Historical Society
PL&C	The Proprietors of the Locks and Canals on Merrimack River
PL&C-Baker	Locks and Canals Collection, Baker Library Historical Collections, Harvard Business School
PL&C Directors	Records of the directors and proprietors, Proprietors of Locks and Canals Collection, Lowell National Historical Park
PL&C-LNHP	Proprietors of Locks and Canals Collection, Lowell National Historical Park

Introduction

p. 1, #1. *Hand-Book for the Visiter to Lowell* (Lowell, MA, 1848), 7.

p. 2, #1. The standard work on waterpower is Louis Hunter, *Waterpower in the Century of the Steam Engine*, Vol 1, of *A History of Industrial Power in the United States* (Charlottesville, 1979). See also the 1880 Census volume mentioned in the text and Robert B. Gordon and Patrick M. Malone, *The Texture of Industry: An Archeological View of the Industrialization of North America* (NY, 1994), 60-63, 95-101.

p. 2, #3. James Montgomery, *A Practical Detail of the Cotton Manufacture of the United States of America* (Glasgow, 1840), 16, 162.

p. 3, #1. *Hand-Book*, 9, 34.

p. 3, #2. Adams and Clay quoted in Thomas W. Lewis, *Zanesville and Muskingum County, Ohio*, 3 vols. (Chicago, 1927), 1: 361-65.

p. 3, #3. Gordon and Malone, *Texture of Industry*, 298

p. 3, #4. *Ibid.*, 298-299; Slater Mill, online data at Library of Congress, Historic American Engineering Record, HAER RI, 4-Pawt, 3.

p. 4, #1. *Ibid.*, 17, 165-166; Gary Kulik and Patrick Malone, *The Wilkinson Mill*, National Historic Mechanical Engineering Landmark Dedication Program (Pawtucket, RI, 1977), 2-3; Carroll Pursell, *Early Stationary Steam Engines in America* (Washington, DC, 1969), 84; Edward Wilkinson to Elisha Dyer," letter of September 16, 1861, in *Transactions of the Rhode Island Society for the Encouragement of Domestic Industry in the Year 1861* (Providence, RI, 1862), 87-90. For a biographical study of David Wilkinson, see John Johnson. "David Wilkinson: Father of the Machine Tool Industry." Master's Thesis, Bridgewater State College [MA], 1978.

p. 4, #2. Russell Fries, "European vs. American Engineering: Pierre Charles L'Enfant and the Water Power System of Paterson, N.J.," *Northeast Historical Archaeology*, 4 (1975), 68-96. Hunter, *Waterpower*, 208-209; John Reys, *The Making of Urban America* (Princeton, 1965), 263.

p. 5, #1, Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England*, (Cambridge, 1991), 43, 44 (image reversed in this printing). See also Kenneth Mailloux, "The Boston Manufacturing Company of Waltham, Massachusetts, 1813-1848: The First Modern Factory in America" (Ph. D. diss., Boston University, 1957), 86-89, 97, 142. The second mill of the Boston Manufacturing Company was planned in 1815, under construction in 1816-1817, and started operating early in 1818.

p. 5, #2. Nathan Appleton, Journal of 1810, entry for Oct. 16, 1810, Nathan Appleton Papers, Massachusetts Historical Society. Steinberg, *Nature Incorporated*, 39-41; Mark Watson, *Nomination of New Lanark for inclusion in the World Heritage List* (Edinburgh: Historic Scotland, 2000) 20-21, 48, 56-59; Frances Gregory, *Nathan Appleton: Merchant and Entrepreneur, 1779-1861* (Charlottesville, University Press of Virginia, 1975), 49. Gregory notes that Appleton became much more observant of industrial developments after talking with F. C. Lowell in Edinburgh earlier that fall. For an overview of British industrial development see Barrie Trinder, *The Making of the Industrial Landscape* (London, 1982) and Neil Cossons, , *The BP Book of Industrial Archaeology* (Newton Abbot, England, 1973). For broader coverage of utopian concepts, see Howard Segal, *Technological Utopianism in American Culture* (Syracuse, NY: Syracuse U. Press, 2005).

Chapter 1. Harnessing the Merrimack River

p. 8, #1. J. W. Meader, *The Merrimack River: Its Source and Its Tributaries* (Boston, 1869), 40, 46–47; George Swain, “Water-Power of Eastern New England,” *Tenth Census of the United States*, vol. 16 (Washington, DC: GPO, 1885), 71–72, 98–104.

p. 9, #1. Henry A. Miles, *Lowell As It Was, and As It Is* (Lowell, MA, 1845), 14. For geological details, see Pauline Carroll, “A Geological and Hydrological History of the Merrimack River Watershed...,” report on file at CLH.

p. 9, #3. Robert Weible, “Lowell National Historical Park: Historic Resource Study, Part I, Pre-history to 1821,” (March, 1981), 9-11; Wilson Waters, *History of Chelmsford, Massachusetts* (Lowell, MA, 1917), 75-78; Daniel Gookin, “Historical Collections of the Indians of New England,” in *Collections of the MHS for the Year 1792*, vol. 1 (Boston, 1806), 186-87.

p. 9, #4. Meader, *The Merrimack River*, 246-47; Henry Perham, “The Wamesit Purchase,” in *CORHA* 6 (1896-1904): 135-36; Z.E. Stone, “Cotton and Woolen Industries at East Chelmsford, Before the Power Loom” *CORHA* 6 (1896-1904): 48-50; Frederick French, “A Plan of Chelmsford,” 1794, in Massachusetts Archives. There is also a copy of the map in Records A (1837-1865), PL&C-LNHP, and in Weible, “Historic Resource Study,” LNHP, March, 1981. Weible, 52, 56-57, identifies mills owned by Joseph Tyler and Moses Hale, as well as the ironworks of Nathan Ames.

p. 11, #1. JBF memo on Pawtucket Canal, Mar. 1876, DB-8, 393, PL&C-Baker.

p. 11, #2. PL&C Directors 23 Aug. 1792; “Speen’s Brook,” plan of East Chelmsford dated 25 May 1792, in Massachusetts Archives.

p. 12, #2. Duke de Rochefoucauld, quoted by Bland Simpson in *The Sierra Club Wetlands Reader*, ed. Sam Wilson and Tom Moritz (San Francisco, 1996), 29; JBF memo on

Pawtucket Canal.

p. 13, #1. Wilkes Allen, *History of Chelmsford* (Haverhill, MA, 1820), 70.

p. 13, #2. Ibid; PL&C Directors, 11 Sept. 1795, 16 Dec. 1796, and 22 May 1797. The original lock chambers were 32 feet by 150 feet. The history of this canal, and of the several changes in its locks is covered in Anne Booth, "Historic Structure Report: Pawtucket Canal and Northern Canal Lock Structures," (Denver: National Park Service, 1982). See also Al Lorenzo, "The Building of the Pawtucket Canal," (Al Lorenzo, 2005 - copy at CLH), which looks closely at questions regarding the number of lock chambers.

p. 13, #3. PL&C Directors, 14 Sept. and 25 Dec. 1803; Booth, 21-27; Lorenzo, "Building of the Pawtucket Canal," 40-41, 48; William E. Gerber, "Locks and Canals of the Merrimack River," *Canal History and Technology Proceedings*, vol. XXVI (Easton, PA, 2007), 234-235; J. G. Hales, "A Plan of Sundry Farms Etc. At Pawtucket..." (1821), CLH.

p. 15, #2. Benjamin Walker, "The Middlesex Canal," *CORHA* 3 (1887): 273-308; Christopher Roberts, *The Middlesex Canal, 1793-1860* (Cambridge, MA, 1938); Mary Stetson Clarke, *The Old Middlesex Canal* (Easton, PA, 1987); Ronald Shaw, *Canals for a Nation* (University Press of Kentucky, 1990), 11-14; Weible, "Historic Resource Study," 75-78.

p. 16, #1. Zachariah Allen, *The Science of Mechanics* (Providence, RI, 1829), 211, 273-276; David Macaulay, *Mill* (Boston, 1983), 78. Macaulay's illustrations provide the best explanation of governor action. The author consulted with this talented illustrator/writer as he produced *Mill*. See also Otto Mayer, *The Origins of Feedback Control* (Cambridge, MA, 1970), 100-14, and Terry Reynolds, "The Emergence of the Breast Wheel and its Adoption in the United States," in Robert Weible, ed., *The World of the Industrial Revolution* (North Andover, MA, 1986), 72, 75.

p. 16, #2. W. R. Bagnall, "Paul Moody," *CORHA* 3 (1884-87): 67-68.

p. 17, #1. Gary Kulik and Patrick Malone discovered the only governor for a vertical waterwheel known to survive in America. This artifact was in the Moffett Machine Shop in Lincoln, RI and is now in the collections at Slater Mill Historic Site in Pawtucket, RI. It is more complex than early forms illustrated in British and American publications. See, for example, the illustration in Allen, 274, which was the principal model for the re-created 1820's governor installed with the waterwheel in the Wilkinson Mill at Slater Mill Historic Site.

p. 17, #2. F. C. Lowell to Peter Remsden and Co., Dec. 31, 1814, Lowell Collection, Letterbook, vol. 4, MHS; Reynolds, "The Emergence of the Breast Wheel," 64-65; Terry Reynolds, *Stronger Than a Hundred Men: A History of the Vertical Water Wheel* (Baltimore, 1983), 284-85.

p. 17, #3. F.C. Lowell to Peter Remsden and Co., Dec. 31, 1814.

p. 18, #1. Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England* (Cambridge, 1994), 42-48; Frances Gregory, *Nathan Appleton: Merchant and Entrepreneur*, 162-72; Robert F. Dalzell, Jr., *Enterprising Elite: The Boston Associates and the World They Made* (NY, 1993), 38-39.

p. 19, #1. Frederick Coburn, *History of Lowell and its People* (NYC, 1920), vol. 1, 124-27; John Coolidge, *Mill and Mansion* (NY, 1967), 45; Weible, "Historic Resource Study," 62-64; Robert Weible, "'More of a place than represented to have been: East Chelmsford, 1775-1821," in Weible, ed., *The Continuing Revolution*, 17-26; Meader, *The Merrimack River*, 264-265; *Statistics of Lowell Manufactures* (Lowell, 1842); George Baldwin, "A Plan of the Land and Buildings Belonging to the Merrimack Manufacturing Company With the Neighboring Farms, Roads, etc. at Pawtucket in the Town of Chelmsford," (1825). Patrick Malone and

Charles Parrott found this map, which is evidence for many of the conclusions in this book, in the basement vault of the Proprietors of Locks and Canals. It is now in the PL&C collection of the LNHP. See also the J. G. Hales map of 1821, reproduced on page 14.

p. 19, #2. Weible, "Historic Resource Study," 64-75.

Chapter 2. Building a City at the Falls, 1821-1836

p. 21, #1. Nathan Appleton, "Introduction of the Power Loom and Origin of Lowell," in *Development of the American Cotton Textile Industry*, ed. Georges Rogers Taylor (New York, 1969), 17-18.

p. 22, #1. Ibid; See PL& C Directors, Aug. 8, 1792, PL&C-LNHP; Introduction by George Rogers Taylor in *Development of the American Cotton Textile Industry*, XXXI; George Gibb, *The Saco-Lowell Shops* (Cambridge, 1950), 742n; James Montgomery, *A Practical Detail of the Cotton Manufacture of the United States of America....*(Glasgow, 1840), 163; Frances W. Gregory, *Nathan Appleton: Merchant and Entrepreneur, 1779-1861* (Charlottesville, 1975), 174-176; Dan Walsh (NPS archivist) interview for Lowell Offering Show, April 11, 2002.

p. 22, #2. Edward Everett, "Fourth of July at Lowell (1830)," in *The Philosophy of Manufactures: Early Debates over Industrialization in the United States*, ed. Michael Folsom and Steven Lubar (Cambridge, MA, 1982), 285.

p. 22, #3. John A. Lowell, "Patrick T. Jackson," *COHRA* 1 (1874-79): 201; Appleton, "Introduction of the Power Loom," 18.

p. 23, #1. Appleton, "Introduction of the Power Loom," 18-19.

p. 23, #2. Ibid.

p. 23, #3. PL&C Directors, Nov.14, Dec. 26, 1821, and Jan. 8, 1822, PL&C-LNHP.

p. 24, #1. Appleton, "Introduction of the Power Loom," 18-22; Gibb, *The Saco-Lowell Shops*, 64-66, 83-87; Brad Parker, *Kirk Boott: Master Spirit of Early Lowell* (Lowell: Brad Parker, 1985), 31-33, 40-43; Appleton, "Introduction of the Power Loom," 22; Gregory, *Nathan Appleton*, 173-180; Robert F. Dalzell, *Enterprising Elite: The Boston Associates and the World they Made* (NY, 1987), 48.

p. 24, #2. "Plans and Deeds," 1-3, overall plan of lots, deeds #27-33. PL&C-LNHP; J. T. Spofford to Mr. Gilman, Nov. 13, 1872, mss. in CLH.

p. 25, #1. Appleton, "Introduction of the Power Loom," 24.

p. 25, #2. John Coolidge, *Mill and Mansion: A Study of Architecture and Society in Lowell, Massachusetts, 1820-1865* (New York, 1967) 23.

p. 27, #2. Detailed coverage of the locks and transportation function of the Pawtucket Canal is in Anne Booth, "Historic Structure Report: Pawtucket Canal and Northern Canal Lock Structures: Historical Data Section" for the Denver Service Center of the National Park Service (Denver, 1982). Al Lorenzo, "The Building of the Pawtucket Canal," (Al Lorenzo, 2005 - copy at CLH) and William E. Gerber, "Locks and Canals of the Merrimack River," *Canal History and Technology Proceedings*, 26 (Easton, PA, 2007): 215-241, are also useful. Another case study is Michael Raber and Patrick Malone, "Navigation and Waterpower: The Connecticut River's Enfield Canal," *Canal History and Technology Proceedings*, 13 (Easton, PA, 1994):6-47. For an insightful examination of Canadian experience with combined power and transportation canals, see Pauline Desjardins, "Navigation and Waterpower: Adaptation and Technology on Canadian Canals," *IA: The Journal of the Society for Industrial Archeology*, vol. 24, no. 1 (2003), 21-47.

p. 27, #4. Parker, *Kirk Boott*, 32-40. See also Alfred Gilman, "Sketch of the Life of Kirk Boott," *CORHA* 2 (1880-83), 3; JBF, "Kirk Boott and His Experience in the British Army,"

CORHA 3 (1884-87), 326, and Montgomery, *A Practical Detail of The Cotton Manufacture*, 163-164 n. Boott must have developed some competence in engineering while on the job in Lowell: JBF kept a sheet of 1832 power estimates by Kirk Boott in his files: A20, File#107, PL&C-Baker.

p. 28, #1. Gibb, *The Saco-Lowell Shops*, 66; Undated document titled “Calculations No. 2. Water Power & Velocity of Rivers” and attributed to an encyclopedia entry by “Buat,” PL&C-LNHP.

p. 28, #2. Daybook 14, Jan. 12, 1881, 350, PL&C-LNHP; “Proposed Improvement of the Merrimack Canal,” June 26, 1862, Shelf 118, Drawing 203, PL&C-LNHP. For the geology of Lowell see Pauline Carroll, “A Geological and Hydrological History of the Merrimack River Watershed, in its Entirety, from its Formation to the Present,” MA DEM contract #899B-78, Feb. 1, 1979, VEa-d. Al Lorenzo has produced an illustrated monograph on *The Use of Granite in the Lowell Canal System* (Al Lorenzo, 2004) and placed a copy in CLH.

p. 29, #1. MMC MSS., vol. 14 (journal) and vol. 28 (ledger), PL&C-Baker; Charles Cowley, *History of Lowell* (Lowell, 1868), 44-45; John O. Green, “Autobiography” CORHA 3 (1884-87): 233-234.

p. 29, #2. Green, “Autobiography,” 233-35. For discussion of the Boston Associates (investors who were primarily from Boston) and their social/familial/financial connections, see Robert Dalzell, Jr., *Enterprising Elite: The Boston Associates and the World They Made* (NY, 1993). Francois Weil uses his research on Springfield to challenge uses of the expression Boston Associates. See Weil’s “Capitalism and Industrialization in New England, 1815-1845,” in *Journal of American History* (March, 1998), 1334-1354. See also page 41, #2, of this book.

p. 29, #3. Green, “Autobiography,” 233-35.

p. 30, #2. Cowley, *History of Lowell*, 44-45; “A Plan of the Land on the South Side of the Pawtucket Canal Belonging to the Merrimack Manufacturing Company,” (January, 1824), CLH.

p. 30, #3. Green, “Autobiography,” 233-35.

p. 31, #1. PL& C, Directors, (26 December 1821); *Handbook for the Visitor to Lowell* (Boston, 1848), 25.

p. 31, #2. *LHE* (1855), 104, Plate XII.

p. 31, #4. George R. Baldwin, “A Plan of the Land and Buildings Belonging to the Merrimack Manufacturing Company....Pawtucket, in the Town of Chelmsford” (1825), PL&C-LNHP; Booth, “Historic Structures Report,” 34-35. See also JBF Records H, PL&C-LNHP, for a historical sketch written by JBF in October 1870.

p. 32, #1. Boott’s diary quoted in William R. Bagnall, “Sketches of Manufacturing and Textile Establishments . . .,” ed. Victor Clark in 1908 (microfiche), 2157-62.

p. 32, #2. Drawing of Merrimack Mill signed by Patrick Tracy Jackson, 1822, PL&C drawings, CLH. The wheel diameter was planned as twenty-eight feet. All dimensions recorded after completion give thirty feet in diameter, matching the fall selected by Moody. See for example, JBF, “Experiments,” notebook, Dec. 14, 1843, PL&C-LNHP. For the design of high breast wheels, see Terry Reynolds, *Stronger than a Hundred Men: A History of the Vertical Water Wheel* (Baltimore), 282-288, and Terry Reynolds, “The Emergence of the Breast Wheel and Its Adoption in the United States,” in Robert Weible, ed., *The World of the Industrial Revolution* (North Andover, MA, 1986), 55-88. Also useful for comparative perspectives is Richard Hills, “Steam and Waterpower: Differences in Transatlantic Approach,” in the same volume edited by Weible, 35-53. CLH has a number of PL&C waterwheel drawings, including one of the “Old Machine Shop Water Wheel” in 1844, Shelf 109, No. 935. See also the drawing

from Frizell in this book, page 33, which provides good gate control details and shows the main belt drive. For power transmission in factories see Theodore Penn, "The Development of the Leather Belt Main Drive," *IA: Journal of the Society for Industrial Archeology*, 7 (1981), 1-14; Robert Gordon and Patrick Malone, *The Texture of Industry: An Archaeological View of the Industrialization of North America* (New York, 1994) 312-15, 320-21; Louis Hunter, *Waterpower in the Century of the Steam Engine*, vol. 1, of *A History of Industrial Power in the United States* (Charlottesville, 1979), chap. 9; and Louis Hunter and Lynwood Bryant, *The Transmission of Power*, vol 3, of *A History of Industrial Power in the United States, 1780-1930* (Cambridge, MA, 1991), 115-33.

p. 32, #3. David Moody, quoted in James Russell, "Biography of John Dummer," *CORHA* 2 (1880-83): 97; William Worthen comment on Robert Allison, "The Old and the New," *Transactions of the ASME* 16 (1894-95): 747-49.

p. 33. #1. Nathan Appleton, MS. Dated Apr. 15, and surely written in 1823, Nathan Appleton Papers, MHS.

p. 33, #2. Ibid.

p.34, #1. Ibid.

p. 34, #2. MMC Directors Records, Report to the Proprietors, August 9, 1823.

p. 34, #3. Worthen comment, "The Old and the New," 747.

p. 36, #1. William Worthen, "Life and Works of James B. Francis," *CORHA* 5 (1894), 235.

p. 36, #3. See two different plans in January, 1824, with the same title: "A Plan of the land on the South Side of the Pawtucket Canal," shelf 106, drawing 599, CLH.

p. 36, #4. MMC Directors' Records, May 19, 1824. PL&C-Baker.

p. 37, #1, undated plan for what would become the Eastern Canal, shelf 118, drawing 272, PL&C-LNHP.

p. 37, #2. MMC Directors' Records, Oct. 19, 1824.

p. 37, #3. Ibid.

p. 39, #1. Ibid., Nov. 22, 1824.

p. 39, #2, JBF, "the Standard Mill Power at Lowell," memo of Aug. 7, 1858, A18, #90, PL&C-Baker; *Handbook*, 25; "Book of Indentures," PL&C-LNHP;

p. 41, #1. Ibid; Gibb, *The Saco-Lowell Shops*, 67-68; Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England* (Cambridge: Cambridge University Press, 1991), 85-87.

p. 41, #2. P. T. Jackson to Rufus King, Oct. 6, 1824, Lee Papers, "B" Letters of P.T.J., MHS.

p. 41, #3. MMC Directors' Records, February 28, 1825; JBF Records H, 132, PL&C-LNHP; Gibb, *The Saco-Lowell Shops*, 68-69.

p. 42, #2. "Book of Indentures," PL&C-LNHP.

p. 42, #3. Joseph Frizell, assistant to JBF, said they divided the water at Lowell and Holyoke to get "as large an area of ground as possible for the placing of mills and appurtenant buildings." This created many difficulties in managing the system and caused waste of water. He predicted it would not be done again. See Frizell, *Water-Power* (NY, 1905), 414-416.

p. 43, #1. George R. Baldwin, "A Plan of Land and Buildings belonging to the Merrimack Manufacturing Company, with the Neighboring Farms, Roads, etc. at Pawtucket in the Town of Chelmsford" (1825), PL&C-LNHP.

p. 43, #2. Parker, *Kirk Boott*, 43, 55; Gibb, *The Saco-Lowell Shops*, 69.

p. 43, #3. MMC Directors' Records, October 23, 1824.

p. 43, #4. Ibid., June 1, 1825, and Locks and Canals, "Plans and Deeds of some of the Land Acquired by PL&C 1792 to 1928," nos. 58-60, PL&C LNHP.

p. 45, #1. PL&C Directors, Mar. 17, 1826.

p. 45, #2. JBF Records H, PL&C-LNHP, 111.

p.45, #3. *Chelmsford Phoenix*, Oct. 7, 1825, to Feb. 24, 1826; *Merrimack Journal*, Mar. 24, 1826, to Jan. 5, 1827; *Lowell Journal*, Mar. 2, 1827; Records H, 112, PL&C-LNHP. JBF interviewed senior citizens in the 1870s to learn what happened.

p. 46, #1. John McPhee, *The Founding Fish* (NY, 2002), 29-31, 95-98, 255-257. Not only juvenile fish return to the sea. Many shad in New England rivers do not die after spawning but return quickly to the sea. However, since this incident took place in the fall, most of the shad that were let over the dam were probably juveniles in an outmigration. See also Steinberg, *Nature Incorporated*, 173-174, which covers the problems caused by Merrimack River dams to fish moving both upstream and downstream, and Mark Herlihy, "An Environmental History of Lowell, Massachusetts," report for the LNHP, July 8, 2001.

p. 46, #2. Steinberg, *Nature Incorporated*, 169, 172, 181-186.

p. 46, #3. Ibid. Henry David Thoreau, *A Week on the Concord and Merrimack Rivers* (Mineola, NY, 2001), 54, describes old shad returning to the sea in August, followed by young fish in September.

p. 47, #1. Steinberg, *Nature Incorporated*, 29-32, 140-142, 173-186; Gary Kulik, "Dams, Fish, and Farmers: The Defense of Public Rights in Eighteenth-Century Rhode Island," in Herbert Gutman and Donald Bell, eds., *The New England Working Class and the New Labor History* (Urbana: U. of IL Press, 1987), 187-213; Morton Horwitz, *The Transformation of*

American Law, 1780-1860 (Cambridge, MA, 1977), 34-53; Joseph K. Angell, *A Treatise on the Common Law in Relation to Water-Courses* (Boston, 1833), 118-137.

p. 47, #2. JBF researched the origin of the name Merrimack and shared this information with local historian Alfred Gilman, who published “Merrimack River, its Sources, Affluents, etc.” in *CORHA*, 2 (1880-1883), 206-211; Thoreau, *A Week on the Concord*, 51, 71.

p. 48, #1. JBF Records H, 111-121, PL&C-LNHP; “Sketch of Pawtucket Dam,” March, 1923 (with historical development) Shelf 128, No. 1795 and “Pawtucket Dam,” Jan. 21, 1921, Shelf 153, No. 28, PL&C-LNHP.

p. 48, #2. JBF Records H, 119; David Sears to PL&C, PL&C Directors, Dec. 5, 1832. Jan. 2 and July 17, 1833, Mar. 31, 1835; Duncan Hay, “Building ‘The New City on the Merrimack’: The Essex Company and Its Role in the Creation of Lawrence, Massachusetts” (Ph.D. diss., University of Delaware, 1986), 45, fn. 13; Steinberg, *Nature Incorporated*, 89-90.

p. 48, #3. *Statistics of Lowell Manufactures* (Lowell, 1846).

p. 49, #1. Thoreau, *A Week on the Concord*, 153.

p.50, #1. For an environmental critique and a discussion of interests shown by Boston Associates in nature, see Steinberg, *Nature Incorporated*, 15, 70-76, 94-95. More detail on corporate landscaping in Lowell is in Patrick M. Malone and Charles A. Parrott, “Greenways in the Industrial City: Parks and Promenades along the Lowell Canals,” in Patrick M. Malone, ed, *Green Engineering: Parks and Promenades in the Industrial City*, a special theme issue of *IA: The Journal of the Society for Industrial Archeology*, vol. 24. no. 1 (1998): 19-40; Patrick Malone and Charles Parrott, “A Public Ornament of the City: Corporate Greenspace in Lowell, MA,” in Cheryl Kollin, ed., *Engineering Green* (Washington, DC, 2003), 26-30. Also very helpful is Susan Lyons and Beth Frawley, “Northern Canal & Walkway Chronology,” a report

for the Lowell Historic Preservation Commission, 1991, and L. Kasparian, "Lucy Larcom Park – Chronology and Historical Data," a report for the Lowell Historic Preservation Commission, 9 Nov., 1989. For evidence of mill operatives appreciating and cultivating plants, see Chad Montrie, "'I think less of the Factory Than of My Native Dell' Labor, Nature, and the Lowell 'Mill Girls,'" in *Environmental History*, vol. 9. no. 2 (April, 2004): 275-295.

p. 50, #2. Tim O'Rous, "The American Venice," *Lowell Citizen*, Feb. 8, 1884.

p. 50. # 3. By March, 1822, Boott was the agent and treasurer of both the MMC and the PL&C. Parker, *Kirk Boott*, 43, 47, 56. For the roles of corporate officers and managers, see Steven Lubar, "Corporate and Urban Contexts of Textile Technology in Nineteenth-Century, Massachusetts," (Ph. D. diss., University of Chicago. 1983), 41-55.

p. 51, #1. Allen Emmet, "Kirk Boott [Sr.] and the Greening of Boston," *Arnoldia* 47, no. 4 (Fall, 1987): 4-34; Parker, *Kirk Boott*, 40; Harriet Robinson, *Loom and Spindle: or Life among the Early Mill Girls* (NY, 1898), x; Steinberg, *Nature Incorporated*, 72-75. I am grateful to Hunter Dupree for advice on the horticultural and botanical interests of Boott family members.

p. 51, #2. *Essex Gazette* (Salem, MA), Aug. 12, 1825, quoted in John O. Green, "Historical Reminiscences," *Proceedings in the City of Lowell at the Semi-Centennial Celebration of the Incorporation of the Town of Lowell*, Mar. 1, 1876 (Lowell, MA, 1876), x.

p. 51, #4. Quoted in Christopher Roberts, *The Middlesex Canal, 1793-1860* (Cambridge, MA, 1938), 153.

p. 53, #1. JBF, "Pawtucket Canal" memo, March, 1876, DB-8, 392-394, PL&C-Baker; Martins, image of "Lowell," *People's Magazine* 1, no. 26 (8 March, 1834); Photo of canal work in 1887, showing old towpath, ND-1, p. 161, PL&C-Baker; Booth, "Historic Structure Report," 295; Ellen Rosebrock, "Lowell Heritage State Park: Transportation System," by Institute for

Conservation Archaeology, for Department of Environmental Management (November, 1980), 194-96, 302-5; William E. Gerber, "Locks and Canals of the Merrimack River," *Canal History and Technology Proceedings*, 26 (Easton, PA, 2007), 236-37.

p. 53, #4. Peter Lawson to Lowell City Council, Feb. 29, 1876, in *CORHA* 6 (1896-1904): 73-74. I am grateful to Al Lorenzo for help tracking down this source.

p. 55, #3. Russell, "Biography of John Dummer," 97, 101-3; Comments by Samuel Webber and William Worthen on Allison, "The Old and the New," 745-46, 748.

p. 56, #1. Ithamar Beard, "Practical Observations on the Power Expended in Driving the Machinery of a Cotton Manufactory at Lowell," *Journal of the Franklin Institute* 11 (Jan. 1833): 6-15.

p. 56, #2. Kirk Boott to E. Appleton, Treasurer of Hamilton Mfg. Co., Aug. 28, 1832, copy in "Col. Francis," [sic] 1853-1864 notebook, 44, L&C LNHP. See same notebook, 1-4, for a table of waterpower leases, with dates.

p. 57, #1. Penn, "The Development of the Leather Belt Main Drive," 1-14. Penn shows that Ithamar Beard made important contributions to multiple belt drive technology after leaving Lowell and also wrote on the subject.

p. 57, #2. Robert Israel to Lewis Waln, Aug. 9, 1831, in Waln Collection, Historical Society of Pennsylvania. I am grateful for a copy given to me by Steven Lubar and Michael Folsom.

p. 57, #3. Andrew Ure, *The Philosophy of Manufactures* (London, 1835), 13.

p. 59, #1. Joshua Merrill, "Reminiscences of Joel Lewis," *CORHA* 1 (1879): 62-64.

p. 59, #2. See three items in PL&C-LNHP: an 1833-1834 notebook with millyard plans by Boyden; Uriah Boyden, "A Plan of a Part of Merrimack River Between Nashua and Lowell,"

(March 1833); and "Plan of Part of City of Lowell - from surveys made in 1833-34 by U. A. Boyden with additions by James B. Francis, May 1837" An indication of Boyden's diverse interests can be found in *The National Cyclopaedia of American Biography*, vol. XI (NY, 1909), 88.

p. 59, #3. JBF, autobiographical sketch, in PL&C-LNHP, gift of Samuel Francis.

p. 60, #1. Desmond FitzGerald, Joseph P. Davis, and John R. Freeman, "James Bicheno Francis: A Memoir," *Journal of the Association of Engineering Societies* 13 (Jan. 1894): 3.

p. 60, #2. JBF Records H, 120, PL&C-LNHP.

p. 61, #1. FitzGerald, Davis, and Freeman, "James Bicheno Francis," 1-3.

p. 61, #2. PL&C Directors, Aug 1, 1835 and Sept. 12, 1840.

Chapter 3. Expanding the Waterpower, 1836-1847.

p. 62, #1. *Statistics of Lowell Manufactures* (Jan. 1, 1837 and Jan. 1, 1842). The 1842 *Statistics* contain an historical sketch with population data. For detailed coverage of the Boott Mill, with a perceptive analysis of management, labor, and production technology, see Laurence Gross, *The Course of Industrial Decline: The Boott Cotton Mills of Lowell, Massachusetts, 1835-1955* (Baltimore, 1993).

p. 63, #1. *Statistics* (Jan. 1, 1837 to Jan. 1, 1845); P. T. Jackson report, PL&C Directors, Sept. 21, 1841, PL&C-LNHP; George Gibb, *The Saco Lowell Shops* (Cambridge, 1950), 98-100. Gibb shows how corporations helped each other out with funds during the financial crisis. However, the value of L&C stock fell from 1836 to 1842, and there were concerns about the end of large textile machinery orders after the Massachusetts contracts were filled.

p. 63, #2. *Statistics* (Jan 1. 1835); Gibb, *The Saco-Lowell Shops*, 70-76, 81-82, 90-94;
JBF to Benjamin Saunders, Oct. 21, 1864, DB-3, 565-571.

p. 63, #3. Plan of Swamp Locks area, c. 1830, Shelf 124, Drawing 2915, PL&C-LNHP;
Gibb, *The Saco-Lowell Shops*, 82-83.

p. 64, #3. PL&C Directors, Report by JBF, 5 February 1848. Here Francis defines
ordinary and extraordinary low water.

p. 65, #1. Richard Greenwood and Patrick Malone, "The Mill as a System," a report from
The Center for History Now to the Lowell National Historic Park (Oct. 28, 1983). See also
Richard Greenwood, "'Scientific Engineering and Useful Improvements': The Manufacturing
Career of Zachariah Allen, 1822-1872" (Ph. D. diss., Brown University, 1996), 69-70.

p. 65, #3. JBF to Theodore Lyman, Oct. 28, 1865, PL&C-Baker, DB-3, 719-721. This
refers to the use of surplus power but offers a fine description of how more flow produces more
friction head losses and thus draws the water down even more: "...the trouble continues in an
increasing ratio."

p. 66, #1. P. T. Jackson to Directors, Sept. 13, 1839, A1, #7, PL&C-Baker.

p. 67, #1. "Plan of the Proposed Canal from Pawtucket Dam to the Western Canal," Shelf
114, Drawing 1, PL&C-LNHP. Baldwin also produced a detailed set of canal sections in 1839,
based on surveys done in June and July: J. F. Baldwin, "Experiments...1839," PL&C-Baker,
NG1, 14-22. For a description of the plan, see P. T. Jackson to Directors, Sept 13, 1839.

p. 67, #2. P. T. Jackson to Directors, Sept. 13, 1839, A1, #7, PL&C-Baker.

p. 67, #3. Ibid.

p. 68, #1. "Report of the Committee on the Subject of a New Canal" (Boston, 1840), 4-5.

p. 68, #2. Ibid., 11.

p. 69, #1. Ibid., 12-13.

p. 69, #2. Ibid., 14-15, 20.

p. 69, #4. PL&C Directors, Jan. 9, 1841.

p. 69, #5. PL&C Directors, Feb. 19, 1839, and Report by P. T. Jackson, Sept. 10, 1840
(also in PL&C Directors).

p. 70, #1. PL&C Directors, Sept. 20, 1842.

p. 70, #2. Ibid., Sept. 9, 1842; Oct. 14, 1842; Jan. 28, 1843; and May 29, 1843.

p. 71, #1. Christopher Roberts, *The Middlesex Canal, 1793-1860* (Cambridge, 1938), 148-158, 183; Michael Folsom, Laurence Gross, and Patrick Malone, "Middlesex Canal Survey" for Industrial Archeology Associates and the Middlesex Canal Commission (1979); JBF, "Pawtucket Canal" memo, March, 1876, DB-8, 392-394, PL&C-Baker; Anne Booth, "Historic Structure Report: Pawtucket Canal and Northern Canal Lock Structures" (Denver: National Park Service); Ellen Fletcher Rosebrock "Lowell Heritage State Park: Transportation System," report for DEM of MA by Institute for conservation Archaeology, Harvard U., November, 1980; Al Lorenzo, *The Building of the Pawtucket Canal* (Al Lorenzo, 2005 - copy at CLH).

p.71, #2. HAER team directed by the author and Charles Parrott found the remains of the Lower Western Canal lock in 1974. Plan Book A, p. 15 (now in PL&C-LNHP, with a photocopy in HAER survey, 1975) has a plan showing the locks, probably drawn by Uriah Boyden, c. 1833. Canal toll receipts are in FC 1-3, PL&C-Baker. Rates allowed by 1835 state legislation are on a toll sign in the collections of the Lowell Historical Society (and replicated at the Guard Locks). Forest products predominate. See also Booth, 114, 165.

p. 71, #3. Nicholas W. Norcross, "Lumbering on the Merrimack River," paper read on February 11, 1920, for the Lowell Historical Society, 1-10; "The Spring Drives on the

Merrimack,” *Courier* (April 5, 1872); A19, #101, PL&C-Baker; William E. Gerber, “Locks and Canals of the Merrimack River,” *Canal History and Technology Proceedings*, vol. XXVI (Easton, PA, 2007), 215-241. Maps and atlases at CLH and PL&C-LNHP show the sawmills along the Pawtucket Canal at various times.

p. 72, #1. PL&C Directors, Nov. 9, 1839, Feb 27 and May 2, 1840; JBF, *Lowell Hydraulic Experiments* (Boston, 1855), 104, Plate XII; Booth, “Historic Structure Report,” 288-289.

p. 72, #2. “Tim O’Rous, “The American Venice,” *Daily Citizen* (Feb. 8, 1884); Clairborne Walthall, “People vs. Power,” (honors thesis in Urban Studies, Brown University, 2002), 41-49; “Book of Useful Information,” 11, PL&C-LNHP.

p. 72, #3. *Lowell Courier*, Apr. 28, 1840.

p. 73, #1. Ibid.

p. 73, #2. Gibb, *The Saco-Lowell Shops*, 98-101.

p. 73, #3. PL& C Directors, Sept. 21, 1841, Sept. 25, 1844, March 10, 1845, and April 5, 1845.

p. 74, #1. Gibb, *The Saco-Lowell Shops*, 102-103; PL& C Directors, Oct. 26, and Dec. 6, 1844, Nov. 19 and 29, 1845. The Proprietors of Locks and Canals on Merrimack River Auction Catalogue for April 15, 1845 is located in the Oversize Files - LF.P9456 at CLH.

p. 74, #2. Gibb, *The Saco-Lowell Shops*, 102-3.

p. 75, #1. JBF to Benjamin Saunders, Oct. 21, 1864, DB-3, 568, PL&C-Baker.

p. 75, #3. PL& C Directors, Sept. 27, 1845. For roles of corporate officers, see Steven Lubar, “Corporate and Urban Contexts of Textile Technology in Nineteenth-Century Lowell, Massachusetts,” (Ph. D. diss., U. of Chicago, 1983), Chap. 1.

p. 76, #1. JBF to John Morse, Dec. 6, 1845, A34, #177, PL&C-Baker.

p. 77, #1. William Worthen, "Life and Works of JBF," in *CORHA* 5 (1894): 232.

p. 77, #2. For more details on corporate landscaping in Lowell and the role of Francis as a "green" engineer, see Patrick Malone and Charles Parrott, "Greenways in the Industrial City: Parks and Promenades along the Lowell Canals," in Patrick Malone, ed., *Green Engineering: Parks and Promenades in the Industrial Community*, a theme issue of *IA: The Journal of the Society for Industrial Archeology*, vol. 24, no. 1 (1998): 19-40.

p. 77, #3. M, "Shade Trees," *Lowell Offering*, ser.2, vol. 1 (1841): 233.

p. 77, #4. *Webster's New World Dictionary of the American Language* (New York, 1970), 857. The term also referred to a game and would later be applied to certain shopping areas. See "Shattuck Mall" and James Francis' use of "mall" later in this article. For an impressive explanation of the New England fascination with elms, see Thomas Campanella, *Republic of Shade: New England and the American Elm* (New Haven, 2003). Campanella, however, overlooks the extensive planting of elms by corporations in Lowell and other industrial communities of the region.

p. 79, #2. J.L.B. [Josephine Baker], "The Factory Girl," *Lowell Offering*, ser. 2, vol. 5 (1845): 274.

p. 79, #3. Lucy Larcom, *A New England Girlhood* (1889; Gloucester, MA, 1973 reprint) 163; Lucy Larcom to Charles Cowley, Feb. 28, 1876, in *Proceedings in the City of Lowell . . .* (Lowell, 1867), 93-95; Worthen, "Life and Works of JBF," 237.

p. 79, #4. John Morse to JBF, Sept. 27, 1845, DA-2A, 32, PL&C-Baker; Paul Hill, "Personal Reminiscences of Lowell, Fifty Years Ago," *CORHA*, 5 (1894): 279. The list of mall plantings is in [William Boott] "Trees and Shrubs in Shattuck Street Mall," A21, #111, PL&C-Baker.

p. 80, #1. Deed, PL&C to Benjamin F. French and George H. Carleton, Mar. 20, 1844. Copy at Middlesex North Registry of Deeds (Lowell), Book 46, p. 138.

p. 80, #2. Thomas Bender, *Toward an Urban Vision: Ideas and Institutions in Nineteenth Century America* (Baltimore, 1975), 88, 168-169, 178-180; Roy Rosenzweig and Elizabeth Blackmar, "Urban Parks," in *Encyclopedia of American Social History III* (New York, 1994), 1689-1695.

p. 80, #3. New England industrial communities that were influenced by the Lowell pattern often had landscaped corridors along power canals. Examples include Dover and Great Falls, NH; Lewiston, ME; and Lawrence and Holyoke, MA. Some smaller mill villages, such as the Crown and Eagle Mills in North Uxbridge, MA also had this feature. For the latter, see William Pierson, Jr., *American Buildings and Their Architects*, vol. 2, part 2, *Technology and the Picturesque: The Corporate and the Early Gothic Styles* (Garden City, NY, 1978), 50-54..

p. 81, #1. Daniel Bluestone, "From Promenade to Park: The Gregarious Origins of Brooklyn's Park Movement," *American Quarterly* 39-4 (Winter, 1987): 529-550; Bender, *Toward an Urban Vision*, 32-36, 41-43, 88, 168-169, 178-180; Rosenzweig and Blackmar, "Urban Parks," 1689-1695. For discussion of model industrial towns, see the introduction and articles by Richard Greenwood and by Arnold Alanen and Lynn Bjorkmann in Malone, ed., *Green Engineering*; Richard Greenwood, "Zachariah Allen and the Architecture of Industrial Paternalism," *Rhode Island History*, vol 45, no. 4 (Nov., 1988); John S. Garner, *The Model Company Town* (Amherst, 1984); John S. Garner, ed., *The Company Town* (New York, 1992); Margaret Crawford, *Building the Workingman's Paradise* (New York, 1995); Richard Candee, "New Towns of the Early New England Textile Industry," in Camille Wells, ed., *Perspectives in Vernacular Architecture* (Annapolis, Md, 1982); Richard Candee, *Atlantic Heights* (Portsmouth,

NH); Kingston Heath, "The Howland Mill Village," *Old Time New England* (1977); Kingston Heath, *The Patina of Place: The Cultural Weathering of a New England Industrial Landscape* (Knoxville, TN, 2001); Gary Kulik, Roger Parks, Theodore Penn, eds., *The New England Mill Village, 1790-1860* (Cambridge, MA, 1982); Stephen Mrozowski, Grace Ziesing, and Mary Beaudry, *Living on the Boott: Historical Archaeology at the Boott Mills Boardinghouses, Lowell, Massachusetts* (Amherst, MA, 1996); Stephen Mrozowski and Mary Beaudry, "Archaeology and the Landscape of Corporate Ideology," in William Kelso and Rachel Most, eds., *Earth Patterns: Essays in Landscape Archaeology* (Charlottesville, VA, 1990), 189-208; David Nye, *America as Second Creation: Technology and Narratives of New Beginnings* (Cambridge, MA, 2003), chap.5; and Gwendolyn Wright, *Building the Dream: A Social History of Housing in America* (Cambridge, MA, 1981), chap. 10.

p. 81, #2. John Greenleaf Whittier, *The Stranger in Lowell* (Boston, 1845), 90-94.

p. 82, #1. *The Protest* (Lowell), Nov. 25, 1848. Copy provided by Michael Folsom, from his extensive collection of materials on Lowell.

p. 82, #2. Israel of Old, *Easy Catechism for Elastic Consciences* (Lowell, 1847), 11-13; Whittier, *The Stranger in Lowell*, 92-93.

p. 82, #3. PL&C Directors, Dec. 4, 1849; JBF, Records A, 181, Oct. 2, 1853, PL&C-Baker.

p. 83, #2. Deed quoted in Shepley, Bulfinch, Richardson, and Abbott, "Suffolk Mfg. Co.," 1979, 6, LNHP; Elisha Huntington, "Address . . ." (Lowell, 1845), 15-16; Journal of Aldermen, vol. 3, April 9, May 5, and Sept. 1, 1845. Bender, *Toward an Urban Vision*, 88. Lowell's commons were early examples of the establishment of municipal parks in this country. Galen Cranz does not begin her periodization of urban park development until

1850. See Galen Cranz, *The Politics of Park Design: A History of Urban Parks in America* (Cambridge, 1982).

p. 84, #1. Samuel Lawrence to Charles Hovey, Feb. 8, 1875, “Three Letters of Samuel Lawrence, Esq.,” *CORHA* 1 (1874-79): 288-89.

p. 84, #2. W. Kenneth Hamblin, *The Earth's Dynamic Systems* (Minneapolis, Minn, 1985), 20–22, 157–60; Robert B. Gordon, “Hydrological Science and the Development of Water Power for Manufacturing,” *Technology and Culture* 26 (1985): 204–35.

p. 85, #1. Greenwood, ““Scientific Engineering and Useful Improvements’ ...” 67-103; Richard Greenwood, “Natural Run and Artificial Falls: Waterpower and the Blackstone Canal,” *Rhode Island History* 49 (May, 1991): 55-56.

p. 85, #2. Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England*, (Cambridge, 1991), 103-104, 107-109; Louis Hunter, *Waterpower in the Century of the Steam Engine*, vol. 1, of *A History of Industrial Power in the United States* (Charlottesville, 1979), 261-264; “Three Letters of Samuel Lawrence,” *CORHA* 1 (1874-1879), 288-291; Arthur Safford, “Merrimack River Storage Improvements,” *Textile World* (Feb. 14, 1925); JBF notebook on the NH reservoirs, in CLH; “NH Reservoirs 1746-1856,” A11, #28, and JBF to PL&C Directors, July 10, 1866, A17, #82, PL&C-Baker. Pauline Carroll shows that Joel Lewis had done studies of NH rivers and lakes for PL&C in the 1830s. See her conclusions in “Lowell Power Canal System, 1792-1848,” Shepley Bulfinch Richardson and Abbott, “Report/ Lowell National Historic Park and Preservation District Cultural Resources Inventory,” vol. 15 (1980), 12-13, LNHP. The inventory forms in that volume are also very useful for any serious student of canal system features.

p. 86, #1. Steinberg, *Nature Incorporated*, 82, 107-114; 260; JBF to Thomas Carey,

“Summary of Payments,” PL&C-Baker, DA-4, 226-233; Francois Weil explains “local dynamism,” and critiques the way scholars have used the terms “Boston Associates” and “Waltham-Lowell System” in “Capitalism and Industrialization in New England, 1815-1845,” *The Journal of American History* (March, 1998), 1334-1354.

p. 86, #2. Merton Sealts Jr., ed., *The Journals and Miscellaneous Notebooks of Ralph Waldo Emerson* (Cambridge, MA, 1973), 10: 102.

p. 86, #3. Henry David Thoreau, *A Week on the Concord and Merrimack Rivers* (Mineola, NY, 2001), 53.

p. 87, #1. D. Spencer Gilman to Moses Jr., Mar. 15, 1846, D. Spencer Gilman Letters in J. I. Little MSS, CLH.

p. 87, #3. Samuel Lawrence to P. T. Jackson, May 1, 1845, A1, #3, PL&C-Baker.

p. 87, #4. JBF Wastebook, no. 5, Jan. 19, 1848, PL&C-LNHP; Gilman to “Canadian friends,” Aug. 22, 1845, D. Spencer Gilman Letters.

p. 88, #2. “Estimate of cost of the Proposed Canal, Feb. 1846,” vol. A 17, PL&C-Baker; PL&C Directors, March 20, 1846 and Sept. 15, 1846.

p. 89, #1. PL&C Directors, Sept. 15, 1846.

p. 89, #2. See extensive series of plans, elevations, and sections of the Northern Canal, Shelf 115, and Jan., 1846, plan of entire canal, Shelf 114, #3, PL&C-LNHP; Franklin Forbes’s Waste Books, # 1-4, 1845-1849, PL&C-LNHP; “Notes Respecting Northern Canal,” A18, #94, “Specifications” for each of 3 sections, and contract with Boody and Ross, C-8, PL&C-Baker; “The Northern Canal,” *Lowell Courier* (Jan. 1, 1848); Patrick M. Malone, “JBF and the Northern Canal,” in Jonathan French, ed., *Boston’s Water Resource Development: Past, Present, and Future* (NY, 1986), 10-18; Donna Mailloux, “JBF and the Northern Canal,” report for LHNP.

Ellen Rosebrock, "Lowell Heritage State Park: Transportation System," by Institute for Conservation Archaeology, for Department of Environmental Management (Nov., 1980) reproduces many key documents, drawings, maps, and photographs relating to the Northern Canal.

p. 91, #2. Samuel K. Hutchinson, "Northern Canal, 1846-1847," in small notebooks, LNHP.

p. 91, #3. "Pay Roll of the Mechanics and Laborers . . .," R-2, PL&C-Baker.

p. 91, #4. Drake, *History of Middlesex County*, II, 80-83; Al Lorenzo, *The Use of Granite in the Lowell Canal System* (Al Lorenzo, 2004 - copy at CLH); H. E. Fletcher, "The Granites of Middlesex," *Contributions of the Lowell Historical Society* 2 (1912) 160-176; Pauline Carroll, "A Geological and Hydrological History of the Merrimack River Watershed..." MA. DEM Contract #899B-78 (Feb. 1, 1979), V.E. c., CLH.

p. 92, #1. Brian Mitchell, *The Paddy Camps: The Irish of Lowell, 1821-1861* (Urbana, 2006), 86-87.

p. 92, #2. Gilman to Moses Jr., July 31, 1846, D. Spencer Gilman Letters.

p. 93, #1. *Lowell Advertiser*, July 21 and 23, 1846; *Lowell Courier*, July 26, 1846, and Oct. 27, 1847. Martha Mayo, director of CLH, has compiled an accident file which suggests that construction work in the millyards at this time was more dangerous than employment on the Northern Canal.

p. 93, #2. *Lowell Courier*, July 9, 1847.

p. 93, #2. *Lowell Advertiser*, Oct. 3, 1846; Gilman to Moses, Jr., Nov. 29, 1846; Gilman to "Brother," March 21, 1847; JBF to John Morse, June 11 and July 27, 1847, vol. A34, PL&C-Baker.

p. 94, #1. Ledger HB-2; T. L. Lawson to JBF, Dec. 18, 1846, A34, #175, both PL&C-Baker.

p. 94, #2. Hill, “Reminiscences,” 281-82.

p. 94, #3. Ibid.

p. 94, #4. July 7, 1847, NH-2, PL&C-Baker.

p. 95, #1. JBF to John Morse, June 29, 1847, A35, #189, PL&C-Baker; “Paul Hill . . . ,” *Lowell Courier-Citizen*, Oct. 31, 1940.

p. 96, #1. *Lowell Courier*, June 24, 1847.

p. 96, #2. Ibid.; PL&C Directors, Feb. 11, 1846; Aug. 4, 1848; Oct. 30, 1848; Peter Molloy, “Nineteenth-Century Hydropower: Design and Construction of Lawrence Dam, 1845-48,” *Winterthur Portfolio*, 15 (1980). Storrow had to alter his dam after building part of it higher than the final elevation set by the committee.

p. 96, #3. PL&C-LNHP has a comprehensive set of drawings for the guard lock, guard gates, and gatehouse; Booth, “Historic Structure Report” and Rosebrock, “Lowell Heritage State Park: Transportation System,” provide much information on the lock.

p. 97, #1. Elevations, Shelf 114, No. 6, PL&C-LNHP. Visitors to the LNHP can see the gatehouse and walk out to its exposed corner on one of the guided tours.

p. 98, #1. Joseph P. Frizell, “Reminiscences of JBF,” *Engineering News*, July 12, 1894, 28-30.

p. 98, #2. “The Northern Canal,” *Lowell Courier*, Jan. 1, 1848.

p. 99, #2. Hill, “Reminiscences,” 281.

Chapter 4. Testing the Waters: Scientific Engineering in Lowell

p. 100, #1. *LHE* (1855), xi.

p. 101, #1. Hiram Mills, "James Bicheno Francis," for the Massachusetts Institute of Technology (Cambridge, MA, Dec. 14, 1892), 5.

p. 101, #2. Uriah Boyden's Scrapbook, 1833-1862, 15-23, and 36-43, CLH. For the earliest known interest in flow measurement at Lowell, see an undated document titled "Calculations No. 2. Water Power & Velocity of Rivers" and attributed to an encyclopedia entry by "Buat [DuBuat]," PL&C-LNHP. This was sent to Kirk Boott in Boston and must date from the early 1820s.

p. 102, #1. PL&C Directors, Sept. 12, 1840, Sept. 20, 1842, and Oct. 14, 1842.

p. 102, #2. *LHE* (1868), 146-148.

p. 102, #3. Storrow's book included applications of calculus which were beyond the mathematical capability of almost all American engineers of the 1830s. See Charles S. Storrow, *A Treatise on Water-Works for Conveying and Distributing Supplies of Water* (Boston, 1835). The most extensive coverage of Storrow's career and connections is in Duncan Hay, "Building the 'New City on the Merrimack': The Essex Company and its Role in the Creation of Lawrence, Massachusetts" (Ph. D. diss., U of DE, 1986). See also Peter Molloy, "Nineteenth-Century Hydropower: Design and Construction of Lawrence Dam, 1845-1848," *Winterthur Portfolio*, 15, No. 8 (Winter, 1980), 315-342; Hunter Rouse, *Historic Writings on Hydraulics* (Iowa City, 1984), 32-33; Charles Sherman, "Great Hydraulic Engineers of New England's Classic Period," *Engineering News-Record*, vol. 107, (Sept. 24, 1931), 476.

p. 103, #1. *LHE* (1868), 148.

p. 103, #2. *Ibid.*, 148-150.

p. 103, #3. Desmond FitzGerald, Joseph P. Davis, and John R. Freeman, "JBF: A

Memoir,” *Journal of the Association of Engineering Societies* 13 (Jan. 1894): 3-4.

p. 104, #1. *LHE* (1868), 151, 155-156.

p. 104, #2. James Russell, “Biography of John Dummer,” *CORHA* 2, (1883): 92-108;

Comments by Samuel Webber and William Worthen on Robert Allison, “The Old and the New,”
Transactions of the ASME, XVI, 745-748.

p. 104, #3. JBF Records A, 125-27, PL&C-LNHP.

p. 104, #4. Worthen, 233; Records A, 64-104, 125-27, PL&C LNHP.

p. 105, #1. Robert Gordon and Patrick Malone, *The Texture of Industry: An Archaeological View of the Industrialization of North America* (NY, 1994), 17-20; Terry Reynolds, “The Emergence of the Breast Wheel and Its Adoption in the United States,” in Robert Weible, ed., *The World of the Industrial Revolution* (North Andover, MA, 1986), 55-88; Robert Israel to Lewis Waln, Aug. 9, 1831, in Waln Collection, Historical Society of Pennsylvania (copy given to me by Steven Lubar and Michael Folsom); Prescott wheel drawings, 1844-45, Shelf 113, #3417 (five), #2578, and Waltham iron wheel drawing, Shelf 121, #2726, CLH; Prescott Mill Foundations notebook, June 11-Dec. 3, 1844, July 30, 1845, PL&C-LNHP. JBF completed, but did not publish, the most thorough set of experiments on an American breast wheel (“Old Machine Shop Water Wheel”) in 1844. For his test data see JBF Records A, 64-103, 126-29, PL&C-LNHP, and “Old Machine Shop Water Wheel” drawing, Shelf 109, #935, CLH.

p. 105, #2. Mary Blewett, ed., *Caught between Two Worlds: The Diary of a Lowell Mill Girl, Susan Brown of Epsom, New Hampshire* (Lowell, MA, 1984), 33-34.

p. 105, #4. Ellwood Morris, “On the Friction Dynamometer, or Brake, of M. de Prony” in *Journal of the Franklin Institute*, 3rd Series, vol 5 [vol. 35] (1843): 225-238; Ellwood Morris’

translation of Arthur Morin, “Experiments on Water-Wheels, Having a Vertical Axis, Called Turbines,” and Ellwood Morris, “Experiments on the Useful Effect of Turbines in the United States,” in *Journal of the Franklin Institute*, 3rd Series, vol. 6 [vol. 36] (1843): 234-246, 289-302, 370-377, 377-384; *LHE* (1855), 1-2; Edwin Layton, “Scientific Technology, 1845-1900: The Hydraulic Turbine and the Origins of Industrial Research,” *Technology and Culture*, 20 (Jan, 1979), 67-70; Edwin Layton, *From Rule of Thumb to Scientific Engineering: JBF and the Invention of the Francis Turbine* (Stony Brook, NY, 1992), 28-35; Edward W. Constant, “Scientific Theory and Technological Testability: Science, Dynamometers and Water Turbines in the 19th Century,” *Technology and Culture* 24 (1983): 183-191; Arthur Safford and Edward Hamilton, “The American Mixed-Flow Turbine and It’s Setting,” *Transactions of the ASCE*, vol. 85, #1503 (1922): 1242-1249; Louis Hunter, *Waterpower in the Century of the Steam Engine*, vol. 1, of *A History of Industrial Power in the United States* (Charlottesville, 1979), 298-324; Norman Smith, *Man & Water: A History of Hydro-Technology* (NY, 1975), 161-179. The author is grateful to Ed Layton for sharing information about JBF and turbine development. He is also grateful to Bruno Belhoste and Jeff Horn for help with translation of French hydraulic engineering sources. See Bruno Belhoste, et al, *Le Moteur Hydraulique en France au XIXe Siecle: Concepteurs, Inventeurs et Constructeurs*, one of *Cahiers d’Histoire et le Philosophie de Science*, Vol. 29 (Paris, 1990).

p. 107, #1. *LHE* (1855), 2-3.

p. 107, #2. Layton, *From Rule of Thumb*, 28; Terry Reynolds, *Stronger Than a Hundred Men: A History of the Vertical Water Wheel* (Baltimore, 1983), 343. JBF stressed the capability of turbines to operate in backwater. See JBF, “Memo on Mr. Boyden’s Patents,” A19, #96, Dec. 1, 1848, PL&C-Baker; and JBF report in PL&C Directors, Feb. 5, 1848.

p. 108, #1. Joseph P. Frizell, "Reminiscences of JBF," *Engineering News*, July 12, 1894, 29. For accomplishments of Hiram Mills, see Richard Hale, "Hiram Francis Mills," memoir in *Proceedings of the ASCE* (Feb., 1924), 226-229. According to Hamilton Hurd, *History of Middlesex County* (Philadelphia, 1890), 50-51, Mayor Luther Lawrence of Lowell was "accidentally killed in the Middlesex Mills by falling into a wheel pit," in 1839.

p. 109, #1. Reynolds, *Stronger Than a Hundred Men*, 342-347; Layton, *From Rule of Thumb*, 28; Charles T. Main, "Evolution of the Transmission of Water Power," in Eveton Foster, ed., *Lamb's Textile Industries of the United States* (Boston, 1916), 224-25.

p. 109, #2. Uriah Boyden, "Paper on Turbines," PL&C General Files, #1076.3, 5-18, PL&C-LNHP; Reynolds, *Stronger Than a Hundred Men*, 191-95; Layton, "Scientific Technology," 68-81, 88-89; Edwin Layton, "JBF and the Rise of Scientific Technology," in Carroll Pursell, Jr., *Technology in America: A History of Individuals and Ideas* (Cambridge, MA, 1990), 96-104; Layton, *From Rule of Thumb*, 35-36; Hunter, *Waterpower*, 328-39.

p. 110, #1. LHE (1868), 18-19.

p. 110, #2. Some weir formulas also account for the number of end contractions (a fixed number that is easily recorded) and the velocity of approach, but the latter is usually not a significant factor in most testing flumes.

p. 111, #1. "JBF" notebook, Dec. 22, 1844, and JBF, "Experiments and Translations" notebook, 5-7, both in PL&C-LNHP. See also JBF "Formulas used at different times..." A18, File #90, PL&C-Baker.

p. 112, #1. LHE, 2-3; Layton, "Scientific Technology," 81; Morris, "On the Friction Dynamometer," 22 5-238; Constant, "Scientific Theory and Technological Testability," 188-193.

p. 112, #2. R. H. Thurston, "The Systematic Testing of Turbine Water-Wheels in the

United States,” *Transactions of the ASME* 7 (1886-87): 364. For addition of a hydraulic regulator during experiments on the Old Machine Shop Water Wheel, see JBF, Records A, 81-93, PL&C-LNHP.

p. 112, #3. *LHE* (1855), 2-6.

p. 113, #1. *Ibid.*; Safford and Hamilton, “The American Mixed-Flow Turbine,” 1251-1252; Layton, *From Rule of Thumb*, 35-40.

p. 113, #2. JBF, “Experiments and Translations” 12-23, 72..

p. 113, #3. James Russell, “Biography of John Dummer,” *CORHA* 2 (1880-83): 101.

p. 115, #1. *LHE* (1868), 55-57, 61-62; Safford and Hamilton, “The American Mixed-Flow Turbine,” 1252-1255; Layton, “Scientific Technology,” 75, 80-81; JBF, “Experiments and Translations,” 100.

p. 115, #2. JBF, “Experiments and Translations,” 73.

p. 115, #3. JBF, “Experiments and Translations,” 146-167, 179-183. The turbine continued to power the gates until electrification of the gatehouse in the twentieth century. When the author conducted an underwater investigation in the wheel pit in 1974, he found the first “Francis Turbine” still intact. It is now an iconic artifact of the LNHP. See Patrick Malone and Robert Weible, “Lowell Water Power System: Pawtucket Gatehouse Hydraulic Turbine,” (Lowell: ASCE/ASME, 1985). Edwin Layton notes that “permanent industrial research laboratories” were a later development but that Francis and “set a scientific style for industrial research that was very influential in America.” See Layton, “Scientific Technology,” 67.

p. 116, #1. JBF memo dated Apr. 15, 1848, quoted in Safford and Hamilton, “The American Mixed-Flow Turbine,” 1345-46.

p. 117, #1. *Ibid.*

p. 117, #2. Boyden, "Paper on Turbines," 4A, 22

p. 119, #1. Ibid., 18.

p. 119, #2. *LHE* (1855), 55-70; Boyden, "Paper on Turbines," 27-28; Safford and Hamilton, "The American-Mixed-Flow Turbine," 1255-1261; Freeman, "JBF: A Memoir," 22; Hunter, *Waterpower*, 335, 338-342, 359-366; Samuel Webber, "Water-Power - Its Generation and Transmission," *Transactions* of the ASME, #DCLXV, vol. XVII (1895-1896): 47-49.

p. 119, #3. *Courier* (August 30, 1870); Mr. Burke to JBF, Lowell Machine Shop proposals, Nov. 1, 1850 and April 21, 1851, A34, PL&C-Baker. Detailed lists of turbines installed over time in Lowell corporations can be found in Book of General Information, Tabulations, Diagrams, etc (in large notebooks), PL&C-LNHP. Gray Fitzsimons gave me the very important *Courier* article, and many others, from his extensive research in Lowell newspapers.

p. 120, #1. *LHE* (1855), 6-7.

p. 120, #2. Ibid.

p. 121, #1. JBF to Boyden, Feb. 1, 1849, JBF, "Experiments and Translations," 185-86.

p. 121, #2. *LHE* (1855), 39.

p. 121, #3. *LHE* (edition abridged for use at MIT, 1885), 12; JBF to Luigi D'Auria, Feb. 25, 1878, A-16, #76, PL&C-Baker.

p. 122, #1. Clemens Herschel, quoted in Hunter Rouse and Simon Ince, *History of Hydraulics* (Iowa City, IA, 1957), 189.

p. 122, #2. Storrow, *A Treatise on Waterworks*, 3-4; Quotation attributed to Sir Cyril Hinshelwood. See George E. Smith, "Newtonian Style in Book II of the Principia," in *Isaac Newton's Natural Philosophy*, ed. Jed Z. Buchwald and I. Bernard Cohen (Cambridge, MA,

2001), 286-87.

p. 122, #3. *LHE* (abridged for MIT, 1885), 20.

p. 123, #1. *LHE* (1883), xi.

p. 123, #3. In addition to working on a small scale, most European experts did not test weirs of “considerable length in proportion to depth.” This is the particular application for which Boyden suggested a formula in 1846. Three years later, Boyden also helped Francis with another formula dealing with discharge and provided a demonstration. See *LHE* (1855), 71-75, 80, 99, 117-118, 126-133.

p. 125, #1. *LHE* (1855), 80-102. In 1848, Francis had gone back to the Pawtucket Gatehouse, after testing his hoisting wheel, to investigate the effects of the depth of water on the downstream side of a weir. The remains of a weir are there today in the tailrace.

p. 125, #2. *Ibid*, 103-111, Plates XII-XIII.

p. 127, #1. *Ibid.*, 118-19, 133-35.

p. 127, #2. Layton, *From Rule of Thumb*, 57, 59-61; Hunter, *Waterpower*, 340-341.

p. 128, #1. William E. Worthen, “Life and Works of JBF,” in *CORHA* 5 (1894): 241; G. S. Greene, J. W. Adams, and W. E. Worthen (Memoirs of Deceased Members), “JBF, Past President and Honorary Member,” *Proceedings of the ASCE* 19 (Apr. 1893): 76; Mansfield Merriman, *Treatise on Hydraulics*, 10th ed. (New York, 1916), 394.

p. 128, #3. John R. Freeman, “General Review of Current Practice in Water Power Production,” 1924, PL&C General Files #1076.1, 22, PL&C-LNHP.

p. 128, #4. *Oxford English Dictionary*.

p. 129, #1. Constant, "Scientific Theory and Technological Testability," 183-198; Layton, "Scientific Technology," 84-86; Thurston, "The Systematic Testing of Turbine Water Wheels," 366-373.

p. 129, #2. James Emerson, *Treatise Relative to the Testing of Water-Wheels and Machinery*, 4th edition (Willimansett, MA, 1892), 34.

p. 129, #3. "Tests of Turbine Water-Wheels," *Lowell Vox Populi*, July 30, 1870.

p. 130, #1. "Report...Measurement," 1853, A23, File #120, Baker PL&C-Baker; JBF, *LHE* (1868), 147.

p. 130, #2. Discharge diagram for "Centre Vent Water Wheel at the Boott Cotton Mills" (Mar. 1868) and table of "Quantity of Water Discharged" by a turbine at the Lawrence Manufacturing Company. Copies of both provided to the author by Al Lorenzo.

p. 130, #3. Emerson, *Treatise Relating to the Testing of Water-Wheels*, 34; Thurston, "Systematic Testing of Turbine Water-Wheels," 366-67.

p. 131, #1. Layton, *From Rule of Thumb*, 46-49. See *LHE* (1855), 2-35, and JBF, "Experiments and Translations" notebook (1845-1857), PL&C-LNHP, for evidence of the care Francis took in turbine testing.

p. 131, #2. Thurston, "The Systematic Testing of Turbine Water-Wheels," 366-367.

p. 131, #3. "Tests of Turbine Water-Wheels;" Jan. 24, 1872 page in "Turbine Tests - J. Emerson 1869-1871," notebook in PL&C-LNHP. See also Emerson's comments about his daughter and Miss Charla Adams, who succeeded her in handling "the entire mathematical part of the work"; Emerson, *Treatise*, 5-6.

p. 131, #4. Thurston, "Systematic Testing of Turbine Water-Wheels," 367, 376-378.

p. 132, #2. *Ibid.*, 366-368, 382-387; Emerson, *Treatise*, 39-45.

p. 132, #3. Thurston, "Systematic Testing of Turbine Water-Wheels," 367-68.

p. 132, #4. Ibid., 368-69, 387, 414-20.

p. 133, #1. JBF, "Report on a Test-Trial of a Swain Turbine Water Wheel," *Journal of the Franklin Institute* (April, 1875 reprint). JBF later published "Experiments on the Humphrey Turbine Water-wheel, at the Tremont and Suffolk Mills..." in *Transactions of the ASCE*, #288, Vol. 13 (1884), 295-302. See also, JBF to Hobbs, Feb. 22, 1845 and JBF to Linus Child, July 18, 1856, A22, file #112, PL & C Baker; "Turbines," in *Lowell Courier* (Aug. 30, 1870); Layton, "Scientific Technology," 82-86; Safford and Hamilton, "The American Mixed-Flow Turbine," 1255-1263, 1289-1292; Constant, "Scientific Theory and Technological Testability," 198; Hunter, *Waterpower*, 351.

p. 133, #2. *LHE* (1855), xi.

p. 133, #3. JBF to Washington Hunt, Jan. 20, 1858, DA5, 5, PL&C-Baker.

p. 134, #1. Worthen, "Life and Works of JBF," 234.

p. 134, #2. JBF, *LHE* (1868), 146-150, 156-158.

p. 135, #1. Thomas Mann, "A Treatise on Rivers and Canals," in *Philosophical Transactions of the Royal Society of London*, vol. 69 (1779), 555-656. See page 577 for rod description. Charles Parrott, historical architect at LNHP, and the author have worked together on the subject of the use of tube floats for flow measurement and plan to soon produce an article with more details and sources than this book provides. This section of the book reflects our joint research on the topic (the sections on corporate landscaping reflect other work we have done together).

p. 135, #2. *LHE* (1868), Preface to Second Edition and 158.

p. 135, #3. Ibid., 191-196.

p. 136, #1. Ibid., 169.

p. 136, #2. Frizell, *Water-Power*, 527, 533-34.

p. 137, #1. For leakage issues and deterioration of turbines, see “Measurements...1871,” small notebook in PL&C-LNHP and Paul Hill to JBF, May 22, 1859, vol. A12, #34, PL&C-Baker. Damaged gages are in Records O, 1876-1882, April 27, 1876, PL&C-LNHP. The 1880 Census provides details on problems, including blockage and obstruction: Swain, *US Census*, 28. See also critical comments by Clemens Herschel, who depended heavily on turbine discharge data at Holyoke: Clemens Herschel, “The Venturi Meter,” in *Transactions of the ASCE*, #371, vol. XVII (Nov., 1888)239. JBF provided caveats about turbine conditions in *LHE* (1868), 147. A much more positive view of turbines as gages is in Thurston, 371, 383.

p. 137, #2. JBF, “Gauging Water Power at Lowell, Mass.,” *Engineering News*, July 25, 1898, 234-35.

p. 138, #1. Frizell, *Water-Power*, 532-33; Lowis Jackson, *Hydraulic Manual* (London, 1883), 142-147.

p. 138, #2. JBF to Benjamin Saunders, Oct. 21, 1864, DB-3, PL&C-Baker.

p. 139, #1. Arthur Frazier, *Water Current Meters in the Smithsonian Collections...* (Washington, DC, 1974), provides a detailed history of current meters and examines some early ones owned by PL&C (pp. 61-63 and Figures 57 and 63). An alternative method became popular in the 20th century. An operator could record rotor revolutions and elapsed time while he moved the meter steadily from the surface to the bottom and back up again. From this data, he calculated the mean current in that vertical path. After completing a series of such measurements spaced across the canal or flume, he used graphical methods similar to those for floats to estimate the mean current in the entire cross section. Of course this

depended on a perfectly functioning meter and consistent vertical movement of that instrument. This method is described in a correspondence course from the International Textbook Company *Hydraulics* (Scranton, PA, 1907), Part 2, #38, 37.

p. 139, #2. *LHE* (1868), 156.

p. 139, #3. JBF to Buff & Berger, Feb. 22, 1881, in Records O, 1876-1882, PL&C-LNHP. By 1888, Herschel, the brilliant inventor of the Venturi meter for easy measurement of flow in large pipes or penstocks, had turned negative on current meters. He criticized the difficulty in rating them, their “delicacy,” and problems in their use by “the average engineer’s assistant.” See Herschel, “The Venturi Meter.”

p. 139, #4. Frazier, 86; Merriman, *Treatise on Hydraulics*, 4-5.

p. 141, #1. JBF to Colonel Francis, Apr. 10, 1879 (#11 of European tour), Francis Family Collection, LNHP; JBF to Buff & Berger, Feb. 22, 1881, JBF Records O; “Stock Account, 1885-1893,” Jan. 1, 1885, both PL&C-LNHP.

p. 142, #1. “Experimental Comparison of Some Different Methods of Measuring the Flow of Water,” *Proceedings of the Society of Arts* [at MIT], Meeting 356 (1886-87), 59.

p. 142, #2. *LHE* (1868), 196.

Chapter 5. Protecting the People and the Profits, 1847-1865

p. 144, #2. Arthur Gilman, “The Freshet of 1831,” *CORHA* 3 (1884-87): 270.

p. 144, #3. JBF, “Great Freshets in Merrimack River,” *CORHA*, 3 (1884-1887), 252, 255-6. The “Great Freshets” article was also published in *Vox Populi*, a Lowell newspaper, on Nov. 14, 1885; JBF, Records H, 119, PL&C-LNHP.

p. 145, #1. JBF, “Great Freshets,” 252-254.

p. 145, #2. *Lowell Courier*, Jan. 12, 1841.

p. 145, #4. JBF, "Great Freshets," 252, 256.

p. 146, #1. Ibid., PL&C Directors, Sept. 21, 1847.

p. 146, #2. Anne Booth, "Historic Structure Report: Pawtucket Canal and Northern Canal Lock Structures" (Denver: National Park Service, 1982), 76-77; JBF Records A, 171-172, PL&C-LNHP; JBF, "Great Freshets," 256.

p. 146, #3. JBF Records A, 172, PL&C-LNHP. See also estimate from Sept. 17, 1847, C-86, PL&C-Baker, which includes both timber for "gate across locking chamber" and "stone with grooves for gate."

p. 147, #1. Sam'l. M. Richardson to JBF, Feb. 23, 1850, A34, #176, PL&C-Baker; JBF, "Great Freshets," 256.

p. 147, #2. JBF Records A, 160, 172; PL&C-LNHP; Franklin Forbes Memoranda, Jan. 18, 1877, PL&C-LNHP; JBF, "Experiments and Translations," June 6, 1850 and 129-131, PL&C-LNHP; Ellen Rosebrock, "Lowell Heritage State Park: Transportation System," by Institute for Conservation Archaeology, for Department of Environmental Management (Nov., 1980), 16, 173-175; Booth, "Historic Structure Report," 71-76; JBF "The Preservation of Timber," letter to O. Chanute, Esq., ASCE Preservation of Timber Committee Chairman, with discussion, Paper # 310 in *Transactions of the ASCE* 13 (August, 1884). Copy in bound volume: "Papers by J.B. Francis, 1860-1891," in LNHP Library. There is some conflict in the sources over whether the pine for the gate was Burnettized or Kyanized. JBF clearly stated in Records, A, in February, 1851, PL&C-LNHP, that "The Great drop gate at the Guard Locks of the Pawtucket Canal was Burnettized." He had considered more expensive southern pine (used earlier at the Pawtucket Gatehouse gates at the falls) but went with less costly white pine, which may have been easier to treat for preservation.

p. 147, #3. JBF Wastebook #7, 1849-1850, Feb. 6, 1850, PL&C-LNHP; JBF Records A, 171-172; estimate of Sept. 17, 1847, C-86, PL&C-Baker; Guard Locks plans, Shelf 117, #282, PL&C-LNHP. See also measured drawings of the Guard Locks complex in the Historic American Engineering Record survey of Lowell (Library of Congress holdings). For description of early skepticism, see "Triumph of Francis's Folly," *Boston Daily Globe*, Jan. 3, 1885.

p. 148, #1. *Boston Daily Advertiser*, Apr. 24, 1852; "Triumph of Francis's Folly," *Boston Daily Globe*, Jan. 3, 1885; JBF Records A, 169-172, PL&C-LNHP.

p. 149, #1. JBF, "Great Freshets," 257.

p. 150, #1. *Boston Daily Advertiser*, Apr. 28, 1852; Gilman, "The Freshet of 1831," 272.

p. 150, #2. Christine Rosen, *The Limits of Fire: Great Fires and the Process of City Growth in America* (Cambridge, 1986); *Courier* (May 5, 1871); Broadside of JBF data on Lowell mill fires, January 28, 1886, vol. 85, #464, PL&C-Baker; Betsy Bahr, "New England Mill Engineering: Rationalization and Reform in Textile Mill Design, 1790-1920," (Ph. D. diss., University of Delaware, 1987), 93. There had been a serious fire at the MMC in 1828 that destroyed one mill. The *Courier* listed total fire losses in the city for every year from 1852 to 1870. Only 1854, 1865, and 1866 stand out as bad years, but the losses were still relatively modest: \$118, 675; \$196, 437; \$224, 101. JBF notes 180 fires on corporation property from Feb. 24, 1863 to Jan. 28, 1886. Only 14 caused losses of more than \$1000. None of the 118 fires after January, 1876, reached that minimal level of damage, an amazing record of industrial fire suppression. For the architectural aspects of fire prevention and control, see Sara Wermiel, *The Fireproof Building: Technology and Public Safety in the Nineteenth-Century American City* (Baltimore, 2000).

p. 151, #1. Lowell Fire Department Records, 1845, CLH.

p. 151, #2. James Francis [son of JBF], *Test of the Fire System Belonging to the Proprietors of Locks and Canals* (Lowell, 1897), 4-7; JBF, "On the Means Adopted in the Factories at Lowell, Mass., for Extinguishing Fire," *Journal of the Franklin Institute*, 79, (April, 1865); Bahr, "New England Mill Engineering," 89-131; Pauline Carroll, "Industrial Fire Protection in Nineteenth Century Lowell," research paper on file at CLH, 3-4; Sara Wermiel, *The Fireproof Building: Technology and Public Safety in the Nineteenth-Century American City* (Baltimore, 2000), 104-137. The cisterns also supplied drinking water to some boarding houses in Lowell, according to the "Report of the Joint Special Committee on the Subject of Introducing Water into the City," (Dec. 21, 1848).

p. 151, #3. JBF, "On the Means Adopted." 268-269; Bahr, "New England Mill Engineering," 103

p. 152, #1. PL&C Directors, Apr. 13, 1849; Francis, *Test of the Fire System*, 4; Claiborne Walthall, "People vs. Power: City and Corporation Relations in Nineteenth Century Lowell, Massachusetts," (Senior Honors Thesis, Brown University, 2002), 18-22; Charles Hyde and Charles Parrott, "Locks and Canals Reservoir," in Peter M. Molloy, ed., *The Lower Merrimack River Valley: An Inventory of Historic Engineering and Industrial Sites* (North Andover, MA, 1978). Molloy's edited volume includes site descriptions and histories for sites in Lowell studied by the Historic American Engineering Record in 1974 and 1975.

p. 152, #2. Day Book #15, Jan. 7, 1852; Francis, *Test of the Fire System*, 8-12; Samuel Adams Drake, *History of Middlesex County*, Vol. II, (Boston, 1880), 83-84.

p. 153, #1. "Corporation Influence," in *Courier* (April 2, 1842); Jefferson Bancroft, "List...", report for Mayor and Aldermen, 31 March, 1845; and "Records of Fires," 1863-1900, PL&C volume mainly in JBF hand, both at CLH. The Middlesex fire is listed on June 24, 1866.

The volume includes ample evidence of close involvement with and advice to the city. See also many letters to corporations in Francis's role as fire inspector and advisor after 1850, DA3-DA6, PL&C-Baker. For one of JBF's early studies of hoses, pipes and jets, see Wastebook #5, Oct. 29, 1847, PL&C-LHNP.

p. 153, #2. See A10, #26, PL&C-Baker; Reservoir Expenditures, 1849-1853, FC-3, and two 1858 letters in DA5, 27, 29, all at PL&C-Baker. See also *Lowell Courier*, Jan 30, 1852, May 14, 1852, Dec. 10, 1872; "Report of the Special Joint Committee on the Subject of Introducing Water into the City," Dec. 21, 1848; Jim Beauchesne, "The Water Question, or, Whose River is This?" a memo prepared for Michael Wurm, LNHP, Sept. 16, 1994; Walthall, "Power vs. People," 19-22; and Heidi Vernon-Wortzel, *Lowell: The Corporations and the City* (New York, 1992), 187-191.

p. 154, #3. W C. Appleton to JBF, Dec. 12, 1846; A34, #175, PL&C-Baker.

p. 155, #1. PL&C Directors, Feb. 21 and 28, 1848. See also report of the commission to adjust heights (again), 28, Nov., 1853, in "Sundry Papers" volume (TC175.596), CLH.

p. 155, #2. "Raising the Water in the Pawtucket Canal," in *Lowell Daily Journal & Courier*, July 9, 1851.

p. 155, #3. Ibid.

p. 155, #4. "Col. Francis," 1853-1864 notebook (really JBF), Dec. 15, 1852, 21, PL&C-LNHP.

p. 156, #1. The most complete statement on the many proven advantages (and few disadvantages) of turbines is in a memo that Francis wrote on December 1, 1848. This was in connection with Boyden's offer to sell Locks and Canals a license for his turbine improvements. See A10, #96, PL&C-Baker.

p. 156, #2. JBF report, PL&C Directors, Feb. 21, 1848.

p. 156, #3. Francis tested one of these turbines and reported results in *LHE* (1855), 61-70. Various problems with the Boott Mill site are covered in Laurence Gross, *The Course of Industrial Decline: The Boott Cotton Mills of Lowell, Massachusetts, 1835-1955* (Baltimore, 2000).

p. 157, #1. PL&C Directors, Apr. 14, 1848.

p. 158, #1. Ibid., Feb. 21, 1848.

p. 158, #2. *Statistics of Lowell Manufactures*, Jan., 1847; Jan. 1853.

p. 159, #1. PL&C Directors, April 1, 1853; Sept. 27, 1853; Nov 1, 1853; Dec 7, 1853.

Louis Hunter made one of his few errors in *Waterpower in the Century of the Steam Engine*, vol. 1, of *A History of Industrial Power in the United States* (Charlottesville, 1979, when he said that the additional power “was distributed among the textile corporations in exact proportion to the waterpower leased by each.” See page 264.

p. 159, #2. PL&C Directors, April 1, 1853; Sept. 27, 1853; Nov 1, 1853; Dec 7, 1853.

See Table 5.1 on page 159 of this book.

p. 160, #1. *Statistics of Lowell Manufactures*, Jan.1853 through Jan. 1867. The Middlesex Company, a woolen manufacturer, was the last to give up breast wheels entirely: none were used with water from the Locks and Canals system after 1878. The company still had 12 foot breast wheels for Concord River water in Jan. 1889, and may have run them into the twentieth century.

p. 161, #1. PL&C Directors, Apr. 8, 1857.

p. 161, #2. JBF to J. C, Hoadley, April 27, 1857, A19, #100; JBF to S. Sawyer, Jan. 6, 1857, DA4, 194; JBF to Joseph Adams, Oct. 9, 1857, DA4, 224 (all in PL&C-Baker); drawings,

Shelf 119, #0343-0348, PL&C-LNHP. On the connection between the Pawtucket Dam and the grist mill see Arthur Safford to Frederick Flather, Dec. 1, 1949, PL&C file #1109 (on grist mill), PL&C-LNHP.

p. 161, #3. William Worthen, "Life and Works of James B. Francis," in *CORHA* 5 (1894): 232; JBF Records H, 152, PL&C-LNHP. See also planting efforts in JBF Records A, PL&C-LNHP and in Susan Lyons and Beth Frawley, "Northern Canal & Walkway Chronology," a report for the Lowell Historic Preservation Commission, 1991. For extensive coverage of corporate landscaping in Lowell, see Patrick M. Malone and Charles A. Parrott, "Greenways in the Industrial City; Parks and Promenades along the Lowell Canals," in *IA: The Journal of the Society for Industrial Archeology*, vol. 24, no. 1 (1998), 19-40.

p. 163, #1. JBF to Assessors, Oct. 7, 1858, DA-5, 53, PL&C-Baker.

p. 163, #2. PL&C Directors, March 5, 1847, April 14, 1848. For discussion of what mill operatives thought about nature and plantings, see Chad Montrie, "I think less of the factory than of my native dell': Labor, Nature, and the Lowell 'Mill Girls,'" in *Environmental History*, Vol. 9, No. 2 (April, 2004), 275-295.

p. 163, #4. JBF sketches and notes, Apr. 1, 1848, A18, PL&C-Baker.

p. 165, #1. JBF Records A, Jan. 1, 1859; JBF to P. S. Lincoln, March 5, 1863, DB-3, PL&C-Baker; Charles Cowley, *Illustrated History of Lowell* (Boston, 1868), 137.

p. 165, #3. Charles E. Little, *Greenways for America* (Baltimore, 1990), 7-11. Olmsted's first park was Central Park in New York City, designed with Calvert Vaux. He proposed a greenway along a creek for the University of California at Berkeley in 1865 and in the following year suggested a park way linking Brooklyn's Prospect Park with Coney Island. The first connected park system may be his Buffalo, NY, one of 1868. His planning for the Emerald

Necklace, which includes greenway connectors, began in the mid 1870s. Little credits William H. Whyte with first mentioning the term "greenway" in a publication, in 1959.

p. 166, #1. For discussion of the concept of the sublime, see David Nye, *American Technological Sublime* (Cambridge, MA, 1994), chaps. 1, 5; John Sears, *Sacred Places: American Tourist Attractions in the Nineteenth Century* (NY, 1989), chap. 8; and Leo Marx, *Machine in the Garden* (Oxford, 1970), 196-197, 214, 230, 294.

p. 166, #3. Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England* (Cambridge, 1991), 102-113.

p. 167, #1. Patrick Malone, "JBF and the Northern Canal," in Jonathan French, ed., *Boston's Water Resource Development: Past, Present, and Future* (NY, 1986), 10-18; JBF, "The Standard Mill Power at Lowell," memo of Aug. 7, 1858, in A18, #90, PL&C-Baker; PL&C Directors, Dec. 17, 1853. A typescript of the Directors' Records is in the PL&C-LNHP, with microfilm copies at the PL&C-Baker and at the CLH.

p. 167, #2. PL&C Directors, Dec. 17, 1853; *Water Resources Data Massachusetts and Rhode Island Water Year 1997* (Washington, DC: 1998), 54-57. For flow into the millpond, you have to adjust the modern USGS data from Lowell. You must subtract the Concord River flow which enters the Merrimack below Pawtucket Dam but above the Merrimack River gauging station in Lowell.

p. 167, #3. Charles Storrow to JBF, Aug. 20, 1869, in PL&C Directors.

p. 168, #4. George White, *Memoir of Samuel Slater*, 2nd ed. (Philadelphia, 1836), 267.

p. 169, #2. George Swain, "Water-power of Eastern New England," in *Reports on the Water-Power of the United States*, Vol. 16 of *Tenth Census of the United States* (Washington, DC, 1985), 83-84.

p. 169, #3. Caleb Kirk to E. I. DuPont, Jan. 31, 1828, quoted in Duncan Hay, "Building 'The New City on the Merrimack': The Essex Company and Its Role in the Creation of Lawrence, Massachusetts" (Ph. D. diss., University of Delaware, 1986), 28.

p.170, #2. PL&C Directors, April 12, 1859; "Form of Lease of Water Power at Lowell," 1853, Sundry Papers volume (TC175.596), CLH.

p. 171, #1. JBF to Thomas Carey, May 17, 1858, DA-5, 18-19, PL&C-Baker.

p. 171, #2. JBF to Directors, March 21, 1859, DA-5, 81, PL&C-Baker.

p. 171, #3. PL&C Directors, Nov. 5, 1856, March 21, 1859, April 12, 1859. A depression in 1858 reduced production so much that Francis did no measurements that year.

p. 172, #1. JBF to Thomas Carey, Dec. 6, 1858, DA-5, PL&C-Baker.

p. 172, #2. PL&C Directors, Apr. 12, 1859. For detailed discussion of surplus water, see Patrick Malone, "Surplus Water, Hybrid Power Systems, and Industrial Expansion in Lowell," in *IA: The Journal of the Society for Industrial Archeology*, Vol. 31, No. 1 (2005), 23-40.

p. 173, #1. *LHE* for MIT (1885), 38; *LHE* (1883), 201-202, 239; Lowis Jackson, *Hydraulic Manual* (London: Crosby Lockwood and Co., 1883) 143-145; JBF, *LHE* (1855), 145; Records, 1876-1882, 123, and Day Book #12, 1866-1876, 151, PL&C-LNHP.

p. 173, #2. Payroll D, 1860-1868, Vol. R-4, PL&C-Baker.

p. 173, #3. Records 1866-1875 I, PL&C Collection, Lowell NPS, August 13, 1868, 53.

p. 174, #2. John R. Freeman, "The Fundamental Problems of Hydroelectric Development," *Transactions of the ASME* 46 (1924): 529-31. There is a great deal of information about the adoption and increasing use of steam in Lowell in Marti Frank, "Carrying the Mill, Steam, Waterpower and New England Textile Mills in the 19th Century" (Ph. D. diss., Harvard University, 2008). Ms. Frank is particularly good on "cogeneration" practices in which

steam produced power as well as valuable heat and humidity for textile processes and warming of work spaces. She shows some cases in which the savings from use of exhaust steam made it a less expensive power source than surplus water. The author is grateful for sources she provided him during her doctoral research.

p. 175, #1. P. T. Jackson to Directors, Sept. 13, 1839, A1, #1; JBF to Corliss and Nightingale, Jan. 6, 1854, A2, #14, both PL&C-Baker.

p. 175, #2. Hunter, *Waterpower*, 217-219.

p.175, #3. The combined or hybrid power systems deserve more study than they have received. Although many of these systems were designed to handle occasional shortages of waterpower (during droughts, ice conditions, or floods), they also provided exhaust steam for heat and processing, allowed manufacturers to enlarge mill complexes, and worked particularly well at sites that had surplus waterpower for most but not all of the year. One of the problems with the available data on hybrid power systems is that we may know the horsepower of installed steam engines but not know how often or how hard they were run. That makes it difficult to compare the use of waterpower and steam power at many sites. See Terry Reynolds, *Stronger Than a Hundred Men: A History of the Vertical Waterwheel* (Baltimore, MD, 1983), 321–31; Richard Hills, *Power in the Industrial Revolution* (Manchester, England, 1970), 93–94, 102, 108, 134–40; 161–76; and Neil Cossons, *The BP Book of Industrial Archaeology* (Newton Abbot, England, 1973), 70, 91–92;

p. 176, # 1. Hunter, *Waterpower*, 286–87, 498, 514–29; Louis Hunter, *Steampower*, vol. 2 of *A History of Industrial Power in the United States* (Charlottesville, Va.: Univ. Press of Virginia, 1985), 110; Carroll Pursell, *Early Stationary Steam Engines in America* (Washington, DC: Smithsonian Institution Press, 1969), 84–89, 134; Gary Kulik and Patrick Malone, *The*

Wilkinson Mill: A National Historic Mechanical Engineering Landmark (Pawtucket, R.I.: ASME and Slater Mill Historic Site), 2–4.

p. 176, #2 For discussions of steampower in hybrid systems and of the use of exhaust steam in Lowell, see Malone, “Surplus Water, Hybrid Power Systems, and Industrial Expansion in Lowell” and Frank, “Carrying the Mill: Steam, Waterpower and New England Textile Mills in the 19th Century.”

p. 176, #3. State of Massachusetts, *Fishes, Reptiles, and Birds of Massachusetts* (Boston, 1839), 104-5.

p. 177, #1. Henry David Thoreau, *A Week on the Concord and Merrimack Rivers* (Mineola, NY, 2001), 20.

p. 177, #2. Steinberg, *Nature Incorporated*, 174-187; Molloy, ed., *The Lower Merrimack River Valley*, 41-42. The height of the “Great Stone Dam” varied from 30 feet to 41 feet depending on the conformation of the bottom.

p. 177, #3. JBF Records A, Dec. 26, 1854, 197, PL&C-LNHP.

p. 178, #2. Vernon-Wortzel, *Lowell*, 152, shows that Lowell corporations sold much of their stockpiled cotton for big profits in 1861-62, assuming incorrectly that the war would be over soon. For an example of wartime canal modification see “Proposed improvement of the Merrimack Canal,” Shelf 118, # 203, PL&C-LNHP.

p. 179, #1. *Statistics of Lowell Manufactures* (annual broadside, 1859-1861).

Chapter 6. Controlling the System, 1865-1885

p. 180, #3. *Time Table of the Lowell Mills* (Lowell, 1868); *Statistics of Lowell Manufactures* (Lowell, Jan.1869). See also JBF to Theodore Lyman, Oct. 38, 1865, DB-3, 719-

721, PL&C-Baker: “Usually by morning the water is running over the top of the flashboards. When the mills start, the water begins to fall and by night it is drawn down below the top of the flashboards more or less, depending on the state of the river...”

p. 181, #1. The total number of spindles rose from 403, 696 to 437, 420 between 1860 and 1865. Five years later, the total had reached 526,710. See *Statistics of Lowell Manufactures* (Lowell, Jan., 1861,1866, 1871). In 1863, Francis had said that “very little of the machinery in the cotton mills has been running, during the past year owing to the higher prices of cotton (50 to 70 cents per pound).” See Records A, 235, PL&C-LNHP.

p. 182, #1. The decade of the 1850s saw significant changes in the Lowell workforce and in corporate attitudes. Lowell continued to change during and after the Civil War. That conflict “hastened the transition from a Yankee to an immigrant workforce in the mills.” says Thomas Dublin. See *Women at Work* (NY, 1979), 138-140, 198-200, 205-207, and Thomas Dublin, *Lowell: The Story of an Industrial City* (Washington, DC: National Park Service, n.d.), 65-72. Martha Mayo, director of the Center for Lowell History, has found, however, that not all mills hired Irish and French Canadian workers at an accelerating rate. Some continued to show strong preference for Yankee women through the 1870s. Mayo also notes that there was a surge of Yankee women (including war widows) seeking mill work in Lowell immediately after the war. Statistics supporting Martha’s argument can be found in Robert G Layer. *Earnings of Cotton Mill Operatives, 1825-1914* (Cambridge, 1955); Appendix C, 70-71, is particularly helpful.

p. 182, #2. PL&C Directors, Feb. 17, 1866.

p. 182, #3. JBF to Thomas Carey, Dec. 6, 1858, vol. DA-5, PL&C-Baker; PL&C Directors, April 12, 1859.

p. 183, #1. PL&C Directors, Nov. 3 and Dec. 1, 1870.

p. 183, #2. PL&C Directors, Nov. 5, 1874.

p. 183, #3. JBF report to Directors, Sept. 17, 1855, in “Sundry Papers” volume (TC175.596), CLH; PL&C Directors, Dec. 26, 1874; “Report of the Committee on Surplus Power,” appointed Jan. 29, 1885, A85, File #462, PL&C-Baker. This reduced price did not apply when backwater was caused by ice blockage in the river. At those times there might not be a surplus of water available.

p.184, #1. Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England* (Cambridge, 1991), 85–88, sees the selling of permanent millpowers (often severed from land sales by the 1830s), combined with the payment of an annual rental fee for the right to use those millpowers, as an important example of the “commodification of water.” Payments for the surplus water actually taken (per day) are an even more dramatic illustration of this commodity concept.

p. 184, #2. JBF to Abbott Lawrence, July 2, 1859, A21, #110, PL&C-Baker.

p. 184, #3. Records, 1876–1882, 1 Aug. 1881, 187, PL&C -LNHP.

p. 185, #1. JBF to Thomas Carey, Dec. 6, 1858, in vol. DA-5, PL&C-Baker.

p. 185, #2. Samuel Lawrence to Charles Hovey, Feb. 8, 1875, *CORHA* 1 (1874-79): 291.

p. 185, #3. *Engineering News-Record*, Mar. 29, 1928.

p. 186, #2. Appendix, Shedd & Sawyer Reports, 1883, vol. A17, # 83, PL&C-Baker. The heading of this table is incorrect, but one can see from the cfs data that this is the ratio of capacity to leased amounts.

p.186, #3. Records, vol. 10a (1884–1891), 18, PL&C-LNHP.

p. 187, #1. Francis had begun to lower the river channel and Hunt’s Falls just downstream of the city, resulting in more net drop (head) for mills on the lower level of the canal

system. Flashboards on the dam and higher levels in the improved upper level canals also added head. When you use the new estimate of 33 total feet of head and a conservative turbine efficiency rating of 75% to calculate the value of one mill-power (25 cfs) you get just over 70 horsepower.

p. 187, #2. George Swain, "Water-power of Eastern New England," in *Reports on the Water-Power of the United States*, Vol. 16 of *Tenth Census of the United States* (Washington, DC, 1985), 81.

p.189, #1. *Handbook for the Visitor to Lowell* (Lowell, MA, 1848), 11; *Statistics of Lowell Manufactures* (Lowell, MA, 1866, 1871, and 1881). The Merrimack Print Works could use exhaust steam for heat in its finishing processes, one reason for the early adoption of steam power in that part of the vast Merrimack Mills complex. Steam, whether as engine exhaust or produced simply for heat, was also considered the best way to warm working spaces in the city's mills by 1850. There was an increase in steam power installation during the Civil War years, when most of the textile corporations in Lowell sharply limited or ceased manufacturing. Many of them focused instead on improvement or expansion of their mill complexes. Installing engines or planning for future use of steam power was part of some wartime projects. Because of the production cutbacks, Lowell published no annual statistics between January 1861, and January 1866. The January 1866, *Statistics of Lowell Manufactures*, was the first to include tabular data on steam engines and installed steam horsepower. During the war, the Suffolk Mfg. Company installed an engine, and the neighboring Tremont Mfg. Co. built a boiler house and smokestack with sufficient capacity to handle the needs of an engine when they finally decided to add one. See Ann Booth's report, "Tremont Yard," for the LNHP, Lowell, Mich., n.d., pp. 14, 27. For discussion of another mill complex that used a hybrid power system, see Laurence Gross, *The*

Course of Industrial Decline: The Boott Cotton Mills of Lowell, Massachusetts, 1835–1955 (Baltimore, Md., 1993), 42–43, 54–56. Recent studies of steam power in Lowell include Patrick Malone, “Surplus Water, Hybrid Power Systems, and Industrial Expansion in Lowell,” in *IA: The Journal of the Society for Industrial Archeology*, Vol. 31, No. 1 (2005), 23-40, and Marti Frank, “Carrying the Mill, Steam, Waterpower and New England Textile Mills in the 19th Century” (Ph. D. diss., Harvard University, 2008). Ms. Frank provides important coverage of what she calls “cogeneration” in Lowell. Steam engines produced mechanical power for manufacturing, and exhaust from those engines could then be used to warm factory spaces or to supply heat and humidity for textile finishing processes. She has even found cases in which the use of exhaust steam made steampower actually cheaper than surplus water.

p. 190, #1. Richard Greenwood and Patrick Malone, “The Mill As a System,” report from The Center for History Now to LNHP, Oct. 28, 1983; Robert Gordon and Patrick Malone, *The Texture of Industry: An Archaeological View of the Industrialization of North America* (New York, 1994), 348, 368–69.

p. 190, #2. JBF to Thomas Carey, Dec. 6, 1859, DA-5, PL&C-Baker.

p.191, #3. The best coverage of the northern reservoirs and their impact is in Steinberg, *Nature Incorporated*.

p. 192, #2. Swain, “Water-power of Eastern New England,” 41-42; for the creation of Sudbury River reservoirs after 1872, see William Brutsh, “The Historical Development of Boston’s Water Supply System,” in Jonathan French, ed., *Boston’s Water Resource Development: Past, Present and Future* (NY, ASCE, 1986), 2.

p.192, #4. Steinberg, *Nature Incorporated*, 189–203.

p. 193, #1. JBF testimony, as summarized in “Report of the Joint Special Committee . . . Passage of Fish . . .,” Apr. 1865, MA Senate Document 183, 17.

p. 193, #2. JBF to Storow, Apr. 21, 1866, Essex Co. Collections, MS69, Box 26, ATHM.

p. 193, #3. JBF Records H,10, PL&C-LNHP.

p. 194, #1. Ibid.

p. 194, #2. JBF to E. A. Bracket, clipping in Day Book, 1882-1883 (Col. Francis), June 5, 1883, PL&C-LNHP.

p. 194, #3. Records H, 1866–1879, 120, PL&C-LNHP; William Worthen, “Life and Works of JBF,” *CORHA* 5 (Lowell, MA: Old Residents Historical Assoc., 1894): 234.

p. 195, #1. “Report of the Special Joint Committee on the Subject of Introducing Water into the City,” Dec. 21, 1848, pp. 10-11. Two out of the three alternative plans proposed by William Worthen involved Hunt’s Falls. The third used water power from the Northern Canal. Francis would only consider Hunt’s Falls. See also a later report by another Joint Special Committee, Dec., 1865.

p. 196, #1. On local taxes paid by the corporations (and costs to them for a municipal water system), see *Lowell Daily Citizen & News* (Feb. 20, 1869) and *Lowell Courier* (April 2, 1842); Library holdings of PL&C (now at CLH) included many books and articles on public works and water supply.

p. 196, #2. *Lowell Courier*, Feb. 20, 1869; *Lowell Daily Citizen & News*, Feb. 19, 1869; Nelson Blake, *Water for the Cities* (Syracuse, NY, 1956), 172-173, 234, 255-262. See also Joel Tarr, *The Search for the Ultimate Sink* (Akron, Ohio, 1996); Nelson Blake, *Water for the Cities* (Syracuse, NY, 1956), 172-173, 234, 255-262; and Christine Rosen, *The Limits of Power : Great*

Fires and the Process of City Growth in America (NY, 1986).

p. 196, #3. *Lowell Courier*, Feb. 20, 1869.

p. 197, #1. *Lowell Daily Citizen & News*, Feb. 20, 1869.

p. 197, #2. *Lowell Courier*, Feb. 24, 1869.

p. 197, #3. *Lowell Vox Populi*, Nov. 13, 1869.

p.198, #1. JBF to PL&C Directors, Jan. 6, 1876 and JBF to John Morse, Jan. 6, 1876, vol. DB-8, 366–67, PL&C-Baker. See also Jim Beauchesne, “The Water Question, or, Whose River Is This?”, a memo prepared for Michael Wurm, Sept. 16, 1994, LNHP ; and Claiborne Walthall, “Power vs. People: City and Corporation Relations in Nineteenth Century Lowell, Massachusetts,” (honors thesis, Urban Studies Program, Brown University, Providence, R.I., 2002). By giving in to the city’s demand for river water, Locks and Canals avoided a serious political confrontation on both the local and state level.

p. 198, #2. *Lowell Courier*, Jan. 21, 1873.

p. 198, #3. Unfortunately, faith in the purity of Merrimack River water was unjustified. Lowell’s new water source caused high mortality from Typhoid in the 1880s and 1890s. Mark Herlihy provides details in “An Environmental History of Lowell, Massachusetts,” LNHP report (2001). Helene Desjarlais produced an exhibit at the Mogan Cultural Center and a brochure on “Lowell: A Friend of the People: The Typhoid Epidemic of 1890-91.”

p. 199, #1. PL&C, Directors, Feb. 24, 1885.

p. 199, #2. JBF to Directors, Aug. 17, 1888, in “Legal Papers” volume, PL&C library, CLH.

p. 199, #3. JBF to Charles Storrow, Oct. 27, 1867, Essex Co. Collections, Box 26, ATHM.

p. 200, #1. JBF to Josiah French, Aug. 30, 1858, A17, #82, PL&C-Baker.

p. 200, #2. Worthen, "Life and Works of JBF," 235.

p. 201, #1. JBF Records H, Oct. 25, 1870, p. 50, PL&C-LNHP. Francis complained that the power required to hoist the gates was "greater than can be economically applied by hand."

p. 201, #2. PL&C Directors, Mar. 3, 1870.

p. 201, #3. Ellen Fletcher Rosebrock, "Final Report: Lowell Heritage State Park: Transportation System, ICA 168, (Cambridge: Institute for Conservation Archaeology, Harvard U., 1980), 29-31, 180-183; Peter Molloy, *The Lower Merrimack River Valley: An Inventory of Historic Engineering and Industrial Sites* (N. Andover, MA, 1978), 79. Patrick Malone and historical architect Charles Parrott discovered the turbine still in place during a Historic American Engineering Record (HAER) survey. See also the section drawing of the gatehouse by Michael Connor, on page 114 of Malone, *Waterpower in Lowell*.

p. 202, #1. PL&C Directors, Dec. 28, 1876. For insights into the difficulties faced by Locks and Canals employees, see Steve Turner and Charles P. Scullion, Jr., *Working the Water* (Lowell: Lowell Historical Preservation Commission, n. d.), which is based primarily on interviews with former Locks and Canals workers.

p. 202, #2. Turner and Scullion, *Working the Water*, 6-13. Many of the 19th century procedures were still in use when Turner and Scullion interviewed past and present workers. As a member of the recording team of the Historic American Engineering Record, the author spent time observing operations at the Swamp Locks in the early 1970s, marveling at the quick reactions, manual dexterity, and exceptional judgment that this work required. Electric power was then being generated at multiple locations on both levels of the system.

p. 203, #1. JBF annual report, Sept. 21, 1869. PL&C-Baker.

p. 203, #2. JBF Records H, pp. 109-151, LNHP.

p. 205, #1. James Francis [Colonel], "Biographical Sketch of the Life of Cleveland J. Cheney, *CORHA* 6 (1896-1904): 114-19.

p. 205, #2. JBF Records H, 131, PL&C-LHNP.

p. 205, #3. JBF Records H, pp. 122, 150, and "Measurements...1871," both in PL&C-LNHP.

p. 206, #1. JBF to Directors, Aug. 17, 1888, in "Legal Papers."

p. 209, #1. Hiram Mills, "The Proprietors of Locks and Canals on Merrimack River," copy of a 1907 report for the directors of Locks and Canals, in PL&C Collections, CLH. See also Day Book No. 14, 1876-1881, pp. 316-317, 321-322; and Day Book No. 15, 1881-1892, pp. 18-33, 49-50, both in PL&C Collections, LNHP.

p. 209, #2. Mills, "The Proprietors of Locks and Canals on Merrimack River," 3. For coverage of problems in canal maintenance and operation, as well as details on canal features, see Al Lorenzo, *The Canals that Powered a Textile Empire* (Al Lorenzo, 2006), copy at CLH.

p. 209, #3. JBF to PL&C "Committee on Deepening Hunt's Falls," DB-8, Feb. 1, 1876, PL&C Baker; Worthen, "Life and Works of JBF," 237.

p. 210, #1. See PL&C collections at CLH, LNHP, and Baker Library. Much of the literature survives in the company library of the PL&C or is referenced (or copied) in his many notebooks, scrapbooks, and journals. His voluminous scrapbook of ads and other printed material on turbines, now at CLH, is a tremendous resource for historians of technology.

p. 210, #2. PL&C Directors, May 28, 1849 and Dec. 30, 1850; Paul Hill, "Personal Reminiscences of Lowell, Fifty Years Ago," *CORHA*, 5 (1894): 293.

p. 210, #3. JBF to Col. Francis, Jan. 24, Feb. 3, and May 5, 1879, Francis Family

Collection, LNHP.

p. 211, #1. PL&C Directors, Feb. 2, 1839.

p. 211, #2. JBF to Col. Francis, May 19 and Apr. 10, 1879, Francis Family Collection, LNHP.

p. 213, #1. JBF, "Address," *Transactions of the ASCE* 10 (1881): 190.

p. 213, #2. JBF to Col. Francis, Feb. 3, 1879, Francis Family Collection, LNHP.

p. 213, #3. Ibid., Feb. 16, 1879.

p. 214, #1. "Moving a Large Tree," *Lowell Vox Populi*, July 24, 1875.

p. 215, #1. Worthen, "Life and Works of JBF," 238.

p. 215, #2. PL&C Directors, Dec. 26, 1878, and Feb. 27, 1879.

p. 215, #3. Hiram Mills, "James Bicheno Francis," for MIT (Cambridge, MA, 1892), 6-7.

p. 216, #1. Ibid.; Worthen, "Life and Works of JBF," 230, 238.

p. 216, #2. Mills, 6-7; Lucille Kane, *The Falls of St. Anthony: The Waterfall That Built Minneapolis* (St. Paul: Minnesota Historical Society, 1887); D. W. Van Allen to JBF, April 27, 1888, CLH; Gardiner, R. H. Jr., "Report of the Committee. To the Board of Directors of the Augusta Manufacturing Company," n. d. [1857?], P93#16, CLH. I am grateful to Charles Parrott for the Augusta report which describes Francis as a referee in a local water dispute and says that he was "generally acknowledged in this country as the highest authority upon all subjects connected with Water Power."

p. 217, #1. *Chronicle and Constitutionalist* (Augusta, GA), Mar. 23, 1884.

p. 217, #2. PL&C Directors, Nov. 20, 1884.

p. 217, #3. PL&C Directors, Dec. 16, 1884.

p. 218, #1. "Account...January 1, 1885" in "Stock Account 1885-1893" notebook,

PL&C-LNHP.

Postscript

p. 219, #2. Hiram Mills, "The Proprietors of Locks and Canals on Merrimack River," copy of a 1907 report for the directors of Locks and Canals, CLH; John G. W. Thomas, "The Proprietors of the Locks and Canals on Merrimac River," *Journal of the Boston Society of Civil Engineers* (April, 1957), 61-69; William R. Bagnall, "Sketches of Manufacturing and Textile Establishments . . . ," ed. Victor Clark in 1908 (microfiche), 2065-2130; Pauline Carroll, "Lowell Power Canal System, 1792-1848," Shepley Bulfinch Richardson and Abbott, "Report/ Lowell National Historic Park and Preservation District Cultural Resources Inventory," vol. 15 (1980), 12-13, LNHP; Louis Hunter, *Waterpower in the Century of the Steam Engine*, vol. 1, of *A History of Industrial Power in the United States* (Charlottesville, 1979), chap. 6; Harry Dinmore, "Proprietors of Locks and Canals: The Founding of Lowell," in Arthur L. Eno, Jr., ed., *Cotton was King* (Lowell, 1976), 69-79;

p. 220, #1. Hunter, *Waterpower*, 250-254; Terry Reynolds, *Stronger Than a Hundred Men: A History of the Vertical Water Wheel* (Baltimore, 1983), 276-277.

p. 220, #3. William Worthen, "Life and Works of James B. Francis," *CORHA* 5 (1894): 240.

p. 221, #1. *Ibid.*, 241. See also Edwin Layton, *From Rule of Thumb to Scientific Engineering: JBF and the Invention of the Francis Turbine* (Stony Brook, NY, 1992) and Edwin Layton, "JBF and the Rise of Scientific Technology," in Carroll Pursell, Jr., *Technology in America: A History of Individuals and Ideas* (Cambridge, MA, 1990), 96-104.

p. 221, #3 Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of*

New England (Cambridge, 1991), 107-115, 166-204.

p. 222, #1 There is a great deal of information about the adoption and increasing use of steam in Lowell in Marti Frank, “Carrying the Mill, Steam, Waterpower and New England Textile Mills in the 19th Century” (Ph. D. diss., Harvard University, 2008), which was completed after this book manuscript was submitted. Ms. Frank is particularly good on “cogeneration” practices in which steam produced power as well as valuable heat and humidity for textile processes and warming of work spaces. She shows some cases in which the savings from use of exhaust steam made steam a expensive power source than surplus water. However, in most situations, steam costs were higher than the price of surplus water, and managers tried to use the extra flow. See Patrick Malone, “Surplus Water, Hybrid Power Systems, and Industrial Expansion in Lowell,” in *IA: The Journal of the Society for Industrial Archeology*, Vol. 31, No. 1 (2005), 23-40.

p. 222, #2. Joseph P. Frizell, “Reminiscences of James B. Francis,” *Engineering News*, July 12, 1894, 29; Hiram Mills, “The Proprietors of Locks and Canals on Merrimack River,” copy of a 1907 report for the directors of Locks and Canals, in PL&C Collections, CLH.

p. 223, #1. Frizell, “Reminiscences,” 30; Desmond Fitzgerald, Joseph P. Davis, and John R. Freeman, “James Bicheno Francis: A Memoir,” *Journal of the Association of Engineering Societies* 13 (Jan. 1894), 9. For a description of Francis’s gravestone (made of granite like many of his engineering structures), see Catherine Goodwin, *Mourning Glory: The Story of Lowell Cemetery* (Lowell, 2003).

p. 223, #2. Robert Gordon and Patrick Malone, *The Texture of Industry: An Archaeological View of the Industrialization of North America* (NY, 1994), 315-320; Julia C.

Bonham, "Cotton Textile Technology in America: Three Centuries of Evolutionary Change" (Ph. D. diss. , Brown University, 1979), chap. 4.

p. 223, #3. Laurence Gross, *The Course of Industrial Decline: The Boott Cotton Mills of Lowell, Massachusetts, 1835-1955* (Baltimore, 1993), 94-95; J. A. Hunnewell to M. E. Sperry, Stone & Webster, Inc., Oct. 3, 1927. Letter copy from Charles Parrott, LNHP; Alan Steiner, "The Electrification of Mills on the Lowell Canal System," research paper in a Brown University seminar taught by Patrick Malone, ca. 1980; Arnold Roos, *Technological Considerations in Historic Hydro-Electric Site Selection*, Environment Canada Microfiche Report, Series 473 (1985); Thomas, "The Proprietors of the Locks and Canals on Merrimac River," 66-69; Margaret Parker, *Lowell: A Study of Industrial Development* (Port Washington, NY, 1970), 120-38, 208-10. For Lowell's economic problems and labor struggles in the 20th century, see Mary Blewett, ed., *Surviving Hard Times: The Working People of Lowell* (Lowell, 1982); Mary Blewett, *The Last Generation: Work and Life in the Textile Mills of Lowell, Massachusetts, 1910-1960* (Amherst, MA, 1990); and Marc Miller, *The Irony of Victory: World War II and Lowell, Massachusetts* (Urbana, IL, 1988).

p. 224, #1. Personal Communications with Mel Lezberg, Dec. 18, 2007, and Jan. 10, 2008; Steve Turner and Charles Scullion Jr., *Working the Water* (Lowell: Lowell Historic Preservation Commission, n.d.). I am also grateful for assistance from Charles Parrott and Gray Fitzsimons on the recent history of Lowell's waterpower system.

p. 224, #2. Lawrence Gall, "The Heritage Factor in Lowell's Revitalization," in Robert Weible, ed., *The Continuing Revolution: A History of Lowell, Massachusetts* (Lowell, 1991), 397-405; *Lowell, Massachusetts: Report of the Lowell Historic Canal District Commission to the Ninety Fifth Congress of the United States of America* (Washington, DC, 1977), 14-15, 21-22,

29-47; *Preservation Plan Amendment* (Lowell, 1990), 6-12, 18-21, 26-36; Cathy Stanton, *The Lowell Experiment: Public History in a Postindustrial City* (Amherst, MA, 2006), chap. 3; ; Carolyn Goldstein, “Many Voices, True Stories, and the Experiences We are Creating in Industrial History Museums: Reinterpreting Lowell, Massachusetts,” *The Public Historian*, Vol. 22, No. 3 (Summer, 2000): 129-137; *Lowell National Historical Park, 1978-2008: 30 Years of Preservation and Innovation for Future Generations* (Lowell, 2008).